THE DESIGN OF TIMBER JOINTS USING METAL FASTENERS IN RELATION TO MILLING TOLERANCES FOR TIMBER THICKNESS

by

Soe Tint

Thesis submitted in partial fulfilment of the requirements for the degree of

Master of Science (Forestry)

in the Australian National University

May 1976

ORIGINALITY OF THESIS

Except where specific acknowledgement is given, this thesis is my original work.

U Soe Tint
B.Sc.(For.) (Rgn.)

ABSTRACT

The effect on load carrying capacity of a lack of full penetration of the nails of timber joint fasteners was investigated by relating lack of penetration to the differences in thickness of the members of joints. The differences are in turn related to the machining of the timber.

The tests of joints with differences in thickness of the members and fabricated with three species of timber and with three different types of fastener demonstrated that if the difference in thickness of the members resulted in a loss of penetration of the nails then there would be a reduction in strength of the joint directly proportional to the difference in thickness.

It was concluded that it would be feasible to use sawn timber for roof truss manufacture by careful selection of the sawmill from which timber supplies are drawn, in order to reduce the probability of occurrence of relatively large thicknesses in timber. An increase in the size of fasteners relative to using dressed timber would be necessary.

ACKNOWLEDGEMENTS

I was pleased to be nominated as a Colombo Plan student by the Forest Department, Socialist Republic of the Union of Burma and to receive the Colombo Plan Fellowship which enabled me to visit Australia and study at the Department of Forestry at the Australian National University.

The association with the staff and students from Australian and overseas countries was most rewarding and I am grateful for the experiences and opportunities provided by the Department through the Colombo Plan Scheme. In particular I would like to thank Mr. K.W. Groves and Mr. D.M. Stodart who acted as supervisors of my study programme and the research project. Mr. T.S. Johnson assisted with the preparation of computer programmes for processing and analysing the data.

Ms N. Chin has typed the thesis and Mrs. V. Gurr traced the diagrams.

In acknowledging the contribution made to my training and experience by my visit to Australia I recognize with some sadness the separation from my wife and four children that it has entailed. I am deeply grateful for the patient encouragement of my wife, Tin Tin Nwe.

LIST OF PLATES

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

1.1 INTRODUCTION

Timber connectors have received a great deal of attention by timber engineers over many years as the structural use of timber has always been limited by the need for joints. There are a variety of connectors available including nails, bolts, shear connecting rings and glues.

In recent years a special type of timber connector, a metal fastener, has come to the fore in certain applications and in particular prefabricated timber roof trusses. They are commonly referred to by the very apt name of "Gangnail" plates. This is a particular trade name and there are other fasteners which function in a similar way and also manufactured by punching holes in metal plates to form nails. Plate 1.1 shows the three types of fasteners used in this study – Gangnail, Steelfast, Sanford. The fasteners have made a very substantial contribution toward more efficient use of timber as they have, *inter alia*, enabled small timber sizes to be used and also assisted in the introduction of factory fabrication.

The use of timber roof trusses prefabricated with metal fasteners is now widespread in Australia and this type of roof construction has gained a particularly high acceptance in Canberra in the Australian Capital Territory. Titmus [1972] found that 80% of domestic houses under construction in the Australian Capital Territory at the time of his study used prefabricated trusses. Wymond [1975] suggests that if 50% of all new houses in Australia used trusses about 90,000 m^3 of timber would be saved annually.

The fasteners were developed in the United States of America where they are mainly used with softwood timber. In Australia they are

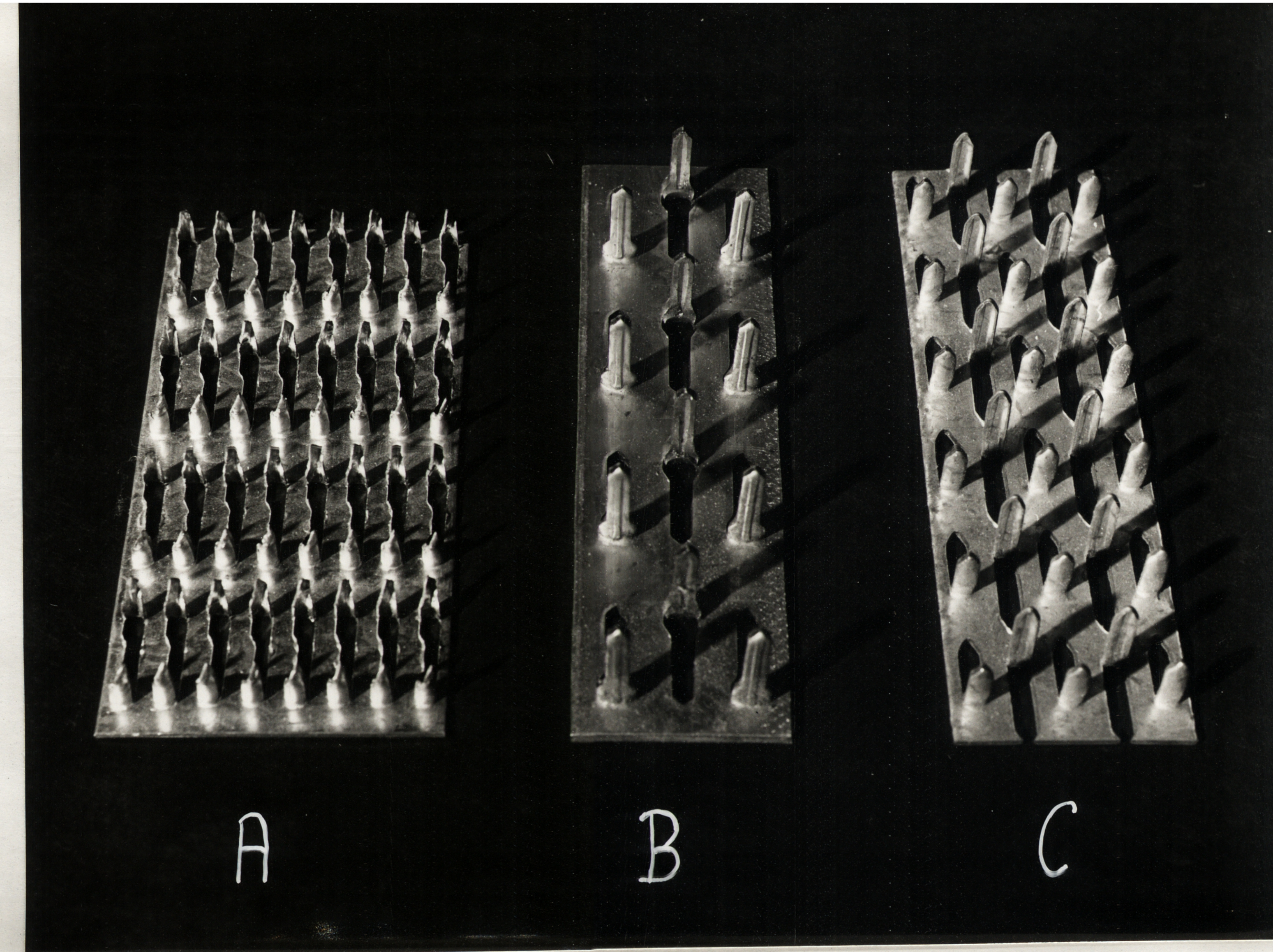


PLATE 1.1

Metal fasteners for timber joints.
Sanford (A), Steelfast (B), Gangnail (C).

commonly used with both hardwoods and softwoods but green hardwood is usually used to enable satisfactory pressing of the nails into the timber. The loads that can be transmitted from one member to another through the metal fasteners are determined by using information set out in manuals supplied by the plate manufacturers.

Optimum use of the fasteners requires that the design of the joint be related to the timber properties and correct specification of the timber and inspection at the time of fabrication are therefore important factors in the design, fabrication and use of the metal fasteners.

There is considerable diversity in specifications relating to timber roof trusses. Stodart [1972] compared four separate specifications applied to the supply of timber roof trusses for government contract houses in the Australian Capital Territory (Table 1.1) and in concluding that the specifications should be reviewed suggested modifications to the specifications.

Requirements that should be met in relation to the fabrication of timber roof trusses include the position of the fasteners, the clearance between the timber members and the plate and the size of the members at the joints.

The tolerance allowed for the position of the fasteners in the specifications summarized in Table 1.1 is that all plates must be positioned within 6 mm (1/4") of location dimensions less than 63.5 mm (2½") and 13 mm (1/2") for other location dimensions. These tolerances, while acceptable in terms of roof truss design and reasonable in terms of fabrication practices, require care in placing the fasteners in position and supervision of checking of the placement is necessary.

The specifications allow a maximum clearance between the plate of the fastener and the timber of 1 mm (1/32").

The size of the timber member is specified in relation to both thickness and width. The tolerance on thickness is 1.5 mm (1/16") and 10 mm (3/8") for the width.

TABLE 1.1

Comparison of specifications for timber roof trusses in the Australian Capital Territory.

x signifies that the item is specified

ITEM	SPECIFICATION I	II	III	IV
Timber				
Conforming to Standards	x	-	-	-
Species	x[1]	x[1]	x[2]	x[1]
Origin	x	x	-	-
Permissible Defects	-	-	x	-
Size Tolerances	-	-	x	x
Plates				
Maximum Clearance to Members	-	-	x	-
Tolerance on Location	-	-	x	-
Zinc Plating	-	-	x	-
Engineering Details				
Computations	x	x[3]	x[4]	-
Detailed Drawings	x	x	-	x
Maximum Number	-	x	-	-
Fabrication				
Name of Fabricator	x	x	x	-
Tolerances	-	-	-	x
Testing				
Number	x	x	-	x
Report	x	x	-	x
Certificates	x	x	-	x
Labelling	-	-	x	x
Service Behaviour	-	x	-	x

1) Hardwood or radiata pine.

2) Yellow stringybark, Tallowwood, Blackbutt, Sydney Blue Gum.

3) If requested.

4) Specified as similar to Gangnail; but builder free to offer an alternative.

The specified tolerances in relation to thickness of the timber are of particular interest in that they determine the milling requirements for the timber and have a considerable effect on the difference in thickness of the members at a joint.

Australian Standard AS 1649-1974 "Determination of Basic Working Loads for Metal Fasteners for Timber" specifies that the thickness of the two members comprising a joint to be tested shall not differ by more than 2 mm.

Differences of thickness of members depends on the machining of the timber and Table 1.2 shows the tolerances for dressed and undressed timber as given in the Australian Standards:

TABLE 1.2

Tolerances on timber thickness.
Australian Standards.[1)]

	Off the Saw	Dressed Timber
Radiata Pine	+3 mm, -0 mm[1a]	+0.5 mm to 1 mm[1b]
Hardwoods	+4 mm, -0 mm[1c]	+1.0 mm to 0 mm[1d]

It seems that meeting the specification for a maximum difference in thickness of 2 mm as implied by Australian Standard 1649 and the 1.5 mm of some specifications shown in Table 1.1 would require that timber for roof trusses must be dressed. In practice it usually is but specially sawn material has been used successfully for many years by some fabricators.

The actual difference in thickness of two members at a timber joint is a matter of chance arising from matching two pieces of wood. While there may be a low probability that a certain difference in thickness between two members of a joint will be exceeded if dressed timber

1) Standards Association of Australia. 1a) AS1490-1973, 1b) AS1492-1973 1c) AS1483-1973, 1d) AS1702-1974

is specified there may be a relatively high probability that it will be exceeded if undressed material is permitted. Investigations of this do not seem to have been reported in the literature.

The significance of a difference in thickness between two members of a joint in a timber roof truss lies mainly in the reduction in the load transferred by the nails of the metal fastener if full penetration of the teeth is not achieved. However the reduction in "load transfer capacity" due to lack of penetration of the nails does not seem to be reported or discussed in the literature.

In this study, seen as a contribution to optimal design of timber roof truss joints, the effect on load-carrying capacity of a lack of penetration of the nails of timber fasteners is investigated with the objective of relating this to the different machining processes that can be used in the preparation of the wood and the differences in thickness of truss members at joints which depend on the machining of the timber.

Examination of timber roof trusses fabricated with green hardwood timber and seasoned timber under service conditions indicated that one consequence of shrinkage of the wood was loss of penetration of the teeth, that is the wood sometimes seemed to have shrunk away from the plate of the fasteners. This loss of penetration of the teeth may account for some of the loss of strength which sometimes occurs as green timber of joints fabricated with metal fasteners is allowed to dry. An investigation of this was also incorporated into this study. The objective was to obtain data to provide a basis for the specification of maximum shrinkage that should be accepted in timber for roof trusses, that is to specify if any species should be excluded from use in timber truss fabrication on the grounds of high shrinkage factors, or if any modifications in the design procedures are necessary to compensate for high shrinkage of the timber.

1.2 STUDY OUTLINE

The study required three lines of investigation:-

1.2.1 The Effect of Lack of Full Nail Penetration on Strength

This investigation is reported in Chapter II. Joints were fabricated with known differences in thickness using three different species of timber and three types of fasteners and tested in tension.

1.2.2 The Effect of Machining Processes on the Difference in Thickness of the Members of Timber Joints

This investigation is reported in Chapter III. Measurements were taken of timber at a number of sawmills and truss-making plants. Measurements at two sections were randomly matched and differences in thicknesses at "synthetic joints" calculated.

1.2.3 Plate Clearances Due to Shrinkage

This investigation is reported in Chapter IV. Plate clearances in fabricated joints were measured when the timber was green and when the timber was dry.

CHAPTER II

THE EFFECT OF CLEARANCE OF METAL FASTENERS ON THE STRENGTH OF TIMBER JOINTS

2.1 INTRODUCTION

It is normal practice in the fabrication of timber roof trusses with metal fasteners to ensure that the plate of the fastener is well pressed into the timber member. If a plate is not pressed flush then the nails do not fully penetrate the timber and there is a reduction in strength of the joint.

It is impracticable to ensure that the thickness of the two members at a joint is always exactly equal and tolerances on the allowable difference in thickness are specified in connection with the fabrication of trusses. Differences in thickness of the timber members at a joint may result in a loss of penetration of the nails of at least one plate on one side of the joint and consequently loss of strength. The investigations to determine the magnitude of this loss of strength are discussed in this chapter.

Radiata pine is commonly used in the fabrication of roof trusses in south-eastern Australia and this timber was selected as one of the timbers investigated. This timber is usually stress graded and the grading is to a large degree determined by the size and number of knots. Australian Standard 1490-1973 "Visually Stress Graded Radiata Pine for Structural Purposes" sets out the requirements for visual grading. However knots are not permitted at joints fabricated with metal fasteners (Australian Standard 1720-1975 "SAA Timber Engineering Code") and the design of joints using radiata pine is not specified in terms of the stress grades. The effect of stress grade on the strength of joints fabricated with radiata pine was therefore incorporated into the main investigation of the effect of a difference in the thickness of the timber members on the strength of the joint.

The fabrication of the joints and the actual testing of the joints in this study had to be undertaken by one person as an assistant was not available within the Department of Forestry. The testing machine in the Department did not have accurate recording equipment to measure strains and it was not therefore practicable to follow some of the usual procedures for testing joints, for example, reading two dial gauges to obtain a load-deflection diagram during a test to failure. Subsequent to the planning and the initial series of tests of this study an Australian standard for the determination of basic working loads for metal fasteners (AS 1649-1974 *op. cit.* p.5) became available. The testing procedures that had been adopted for this study were different in some respects to those specified in the standard. The main differences were in the rate of strain of the joints and the recording of deflections. The results of this study cannot therefore be used for the calculation of basic working loads of metal fasteners in accordance with the procedures specified in the standard. However this was not the objective of the study and consistent procedures ensure valid comparisons between tests.

The commercial equipment and factory techniques for pressing the nails of metal fasteners into timber cover a wide range. In some presses a weight falls on to the fasteners which have been accurately placed over the joint. Hydraulic presses are also used and for the fasteners manufactured from relatively light gauge steel the timber members pass through rollers and the pressing occurs in a wringer-like action. The clearance of the fasteners at a joint after pressing are consequently dependent on the pressing technique and over-pressing could compensate to some extent for a difference in the thickness of the members. In this investigation a pressing technique was developed which ensured that a difference in thickness of the timber members resulted in a plate clearance equal to that difference. The effect of a difference in thickness of timber members on plate clearance is illustrated in Figure 2.1.

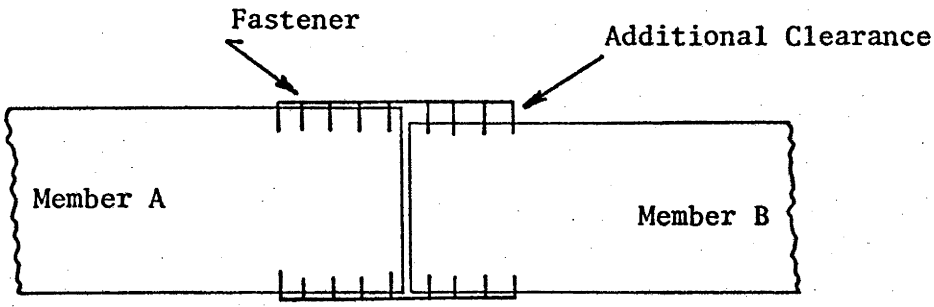


FIGURE 2.1

Plate clearance as a result of a difference in thickness between members.

2.2 MATERIALS AND METHODS

2.2.1 Timber

Timber Species

The following species were selected for the fabrication of joints:

(1) Radiata pine (*Pinus radiata* D.Don)

(2) Karri (*Eucalyptus diversicolor* F.v.M.)

(3) Alpine Ash (*Eucalyptus delegatensis* R.T.Baker)

The species selected are commonly used in Australia for the manufacture of timber roof trusses. They represent a wide range of timber strengths in the group classification adopted for the structural use of timber in Australia. The strength group and other important properties of the three species are given in Table 2.1.

TABLE 2.1

Properties of timber selected for joint fabrication.

SPECIES	STRENGTH[1) GROUP/ STRENGTH[2) GROUP	DENSITY[3) gm/cc Basic	Dry[4)	SHRINKAGE[3),5) % Radial	Tangential	DURABILITY[2) CLASS
Radiata Pine	SD5 SD7/D	0.49	0.59	3	2.5	4
Alpine Ash	S4/C	0.51	0.66	5	8.5	4
Karri	S3/B	0.70	0.91	4.5	10.0	3

1) Australian Standard Timber Engineering Code (AS 1720-1975).

2) Timber Engineering Design Handbook.

3) Division of Forest Products Technological Paper No. 13 [C.S.I.R.O. 1961].

4) 12% moisture content.

5) Green to 12% moisture content.

The range of stress ratings of the timbers in accordance with the structural grades set out in the appropriate Australian Standard are given in Table 2.2.

TABLE 2.2

Stress ratings for structural grades of selected timbers.

SPECIES	AUSTRALIAN STANDARD	STRENGTH GROUP	STRUCTURAL GRADE — STRESS RATING
Radiata Pine	078	S5 S7	Standard Building — 800 f. Select Building — 1000 f. Standard Engineering — 1250 f. Select Engineering — 1600 f.
Alpine Ash	083	S4	Building — 1250 f. Standard — 1600 f. Select — 2000 f.
Karri	1483	S3	Structural 2 — 2000 f. Structural 1 — 2500 f.

Australian timber species have been classified in Australian Standard AS 1720-1975, the Timber Engineering Code, into four joint groups for the purpose of the design of timber joints, namely J1, J2, J3, J4. The species selected for this study are in three of these joint groups, Radiata Pine J4, Alpine Ash J3, and Karri J2.

Timber Quality

The standard procedures for the mechanical testing of timber require the use of selected timber with no significant defects. The timber of all joints fabricated in connection with this investigation met this requirement. An additional special procedure was followed in selecting the radiata pine.

Mechanical stress grading of radiata pine has been developed to assist in overcoming the difficulties associated with relating strength of timber to the size of knots, as is done in visual grading, and this method of grading may gain increasing acceptance, especially in relation to the supply of timber for roof truss fabrication. Although joint design for radiata pine is not directly related to the stress grades obtained by mechanical stress grading (it is all graded as J4 for the purposes of joint design) the radiata pine used in this study was sorted into stress grades using a mechanical stress grader. Defect-free material was selected from the mechanically graded pieces to check, within the framework of the main objective of this section of the study, if the strength of joints was significantly related to the stress ratings. The stress ratings selected were 1600f, 1250f, 1000f, 800f and "rejects".

Sampling of Timber

It is probable that all the radiata pine came from the plantations within the Australian Capital Territory for although timber was collected over a period of about one year from three different sources, namely the Government Sawmill at Canberra, Integrated Forest Products, Canberra, and timber processed through the experimental sawmill at Mount Stromlo, Australian Capital Territory, these mills normally draw log supplies from the plantations in the Australian Capital Territory. Collection of timber from the three sources over a period of one year should ensure that the timber used came from a relatively large number of trees and certainly more than five, as is required in AS 1649-1974 "Determination of Basic Working Loads for Metal Fasteners for Timber".

Karri was obtained through the courtesy of Queanbeyan Roof Trusses and the pieces of timber used for the preparation of the joints were collected over a period of about one year and it can be assumed with certainty that more than five trees are represented in the joints tested.

Alpine Ash was purchased through a timber merchant in Canberra and difficulties were encountered in obtaining green rough sawn material. The source of the material was not definitely known and as it came in one parcel it probably came from a limited number of trees.

Moisture Condition of Timber

The Karri and Alpine Ash were tested in two moisture conditions, green and dry. Two sets of test specimens in each series of tests were prepared using green timber. One set was tested shortly after fabrication with the timber still green and the other set was dried under atmospheric conditions. Drying took several months and the set was then tested in the dry condition. The moisture content of the timber was obtained with an electrical moisture meter. All the joints tested green had moisture contents well above 30%, the average was 45%. The range of moisture contents of the seasoned timber was 10 - 15% and the average 12%.

Radiata pine should only be used for structural purposes in a seasoned condition and all joints of this timber were therefore fabricated with seasoned timber and tested "dry". The moisture contents ranged from 10 - 15% and the average was 12%.

2.2.2 Number of Test Specimens

The number of replications in each set of joints was varied in relation to the difference in thickness between the two members of the joint and the type of fastener used to fabricate the joint.

TABLE 2.3.1

Number of test specimens — Radiata Pine.

DIFFERENCE IN THICKNESS (mm)	TYPES AND SIZES OF FASTENER WIDTH × LENGTH × THICKNESS (mm)			MOISTURE CONDITION	NUMBER OF SPECIMENS	TIMBER GRADE	REMARKS
0 - 9.41	Gangnails	35 × 117 × 1.2	18 gauge	Dried	31	1600f	To study effect of stress grades
0 - 6.35	"	"	"	"	15	1250f	
0 - 6.10	"	"	"	"	10	1000f	
0 - 3.05	"	"	"	"	13	800f	
0 - 6.10	"	"	"	"	10	Reject	
0 - 6.35	Gangnails	38 × 115 × 1.9	14 gauge	"	14	1250f	
0 - 7.60	Steelfast	54 × 90 × 1.9	14 gauge	"	15	1250f	
0- 5.10	Sanford	76x 102x 0.9	24 gauge	"	8	1250f	

The numbers of test specimens are summarized in Tables 2.3.1, 2.3.2, and 2.3.3. The numbers shown include tests undertaken as preliminary work to determine the variation between specimens and to check the proposed procedures and the equipment.

TABLE 2.3.2

Number of test specimens — Alpine Ash (Building Grade).

DIFFERENCE IN THICKNESS (mm)	TYPES AND SIZES OF FASTENER WIDTH × LENGTH × THICKNESS (mm)			MOISTURE CONDITION	NUMBER OF SPECIMENS
0 - 6.35	Gangnails	38 × 115 × 1.9	14 gauge	Green	12
0 - 6.35	"	"	"	Dried	14
0 - 7.60	Steelfast	54 × 90 × 1.9	14 gauge	Green	15
0 - 7.60	"	"	"	Dried	15
0 - 7.60	Steelfast	54 × 120 × 1.9	14 gauge	Green	15
0 - 7.60	"	"	"	Dried	15
0 - 5.10	Sanford	76 × 102 × 0.9	24 gauge	Green	8
0 - 5.10	"	"	"	Dried	6

TABLE 2.3.3

Number of test specimens — Karri (Structural Grade).

DIFFERENCE IN THICKNESS (mm)	TYPES AND SIZES OF FASTENER WIDTH × LENGTH × THICKNESS (mm)			MOISTURE CONDITION	NUMBER OF SPECIMENS
0 - 6.35	Gangnails	38 × 115 × 1.9	14 gauge	Green	14
0 - 6.35	"	"	"	Dried	14
0 - 7.75	Steelfast	54 × 90 × 1.9	14 gauge	Green	30
0 - 8.00	"	"	"	Dried	29
0 - 7.60	Steelfast	54 × 120 × 1.9	14 gauge	Green	15
0 - 7.6	"	"	"	Dried	14
0 - 5.75	Sanford	76 × 102 × 0.9	24 gauge	Green	7
0 - 5.10	"	"	"	Dried	6

2.2.3 Fasteners

Type of Fastener

Three types of connectors were used in this study, Gangnail, Steelfast and Sanford. All of these connectors are in commercial use for the fabrication of timber roof trusses. The dimensional characteristics of the plates used are summarized in Table 2.4.

TABLE 2.4

Dimensional characteristics of metal connectors.

TYPE OF CONNECTOR	DIMENSIONS Length	Width	Thickness mm	Gauge	AREA sq. mm	NUMBER OF TEETH PER PLATE	LENGTH OF TEETH mm
Gangnail	35	117	1.2	18	4095	30	11 14
Gangnail	38	115	1.9	14	4370	16	15
Steelfast	54	90	1.9	14	4860	15	17
Steelfast	54	120	1.9	14	6480	20	17
Sanford	76	102	0.9	24	7752	96	10
Sanford	76	154	0.9	24	11704	144	10

Selection of Fasteners

The connectors used in this study were supplied by truss fabricators in Canberra and Queanbeyan and were not selected either on a random basis or to ensure that all the connectors used in one series of tests were manufactured from the same batch of steel. The connectors are run of the plant but it is probable that they were all from the same batch of steel as all the connectors of each type were obtained at the same time.

Types of Joint

Tension was adopted as the basic test for each joint. The test joint is shown in Plate 2.1. The test joint adopted is the Type I joint specified in Australian Standard AS 1649-1974.

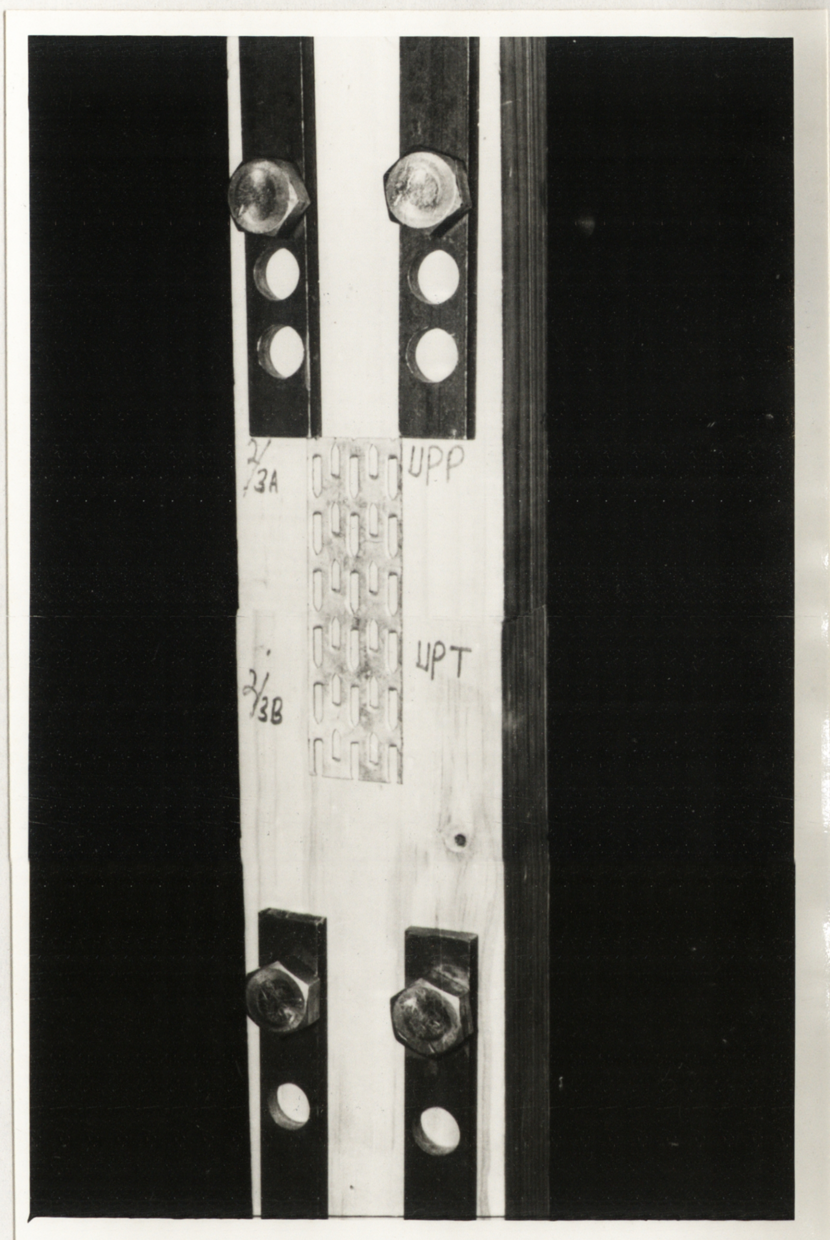


PLATE 2.1

Typical test joint.

Timber: Radiata Pine.
Plate: Sanford.

2.2.4 Preparation of Test Specimens

Timber used in the preparation of the test specimens was 76.2 mm by 38.1 mm wide, that is a normal 3 inch by 1½ inch in the Imperial system of measurements which were in use in Australia when the preliminary testing was undertaken.

The radiata pine was stress graded in the mechanical stress grader at the Department of Forestry, Australian National University, an Isles Computermatic Model MK 3. The grades sorted by the mechanical stress grader were 1600f, 1250f, 1000f, 800f and reject. Timber of each grade was sorted for the experimental work to determine if the strength of the joint was significantly related to stress grades. A relatively large quantity of 1250f marked was sorted for the main investigation of the study, the effect of difference in thickness of the members on strength of the joint.

The Karri and Alpine Ash were visually graded to ensure that all test specimens were fabricated with defect-free timber.

The graded timber was cut into 25.4 cm (10") long pieces. Australian Standard AS 1649-1974 requires that the length of each member of the joint should be not less than the greater of 225 mm and three times half of the length of the connector used at the joint. Adjacent pieces were matched for joint fabrication. End matching reduces the likelihood of density variation between the two members of the joint in the timber where the connectors are pressed.

The matched pieces were numbered to signify a specific joint and randomly allocated as a numbered joint in the series of joint tests with controlled differences in thickness. The members of each joint were dressed in a thicknessing machine to obtain the various differences in thickness required. Particular care was taken in dressing to ensure that flat surfaces were obtained and that the corners of the members were a right angle. The measurements of thickness were taken with a micrometer at three sections on each member where the connector would be pressed. Thickness measurements were taken to one thousandth of an inch and later converted to millimetres.

The pieces of timber to form a joint were clamped end-to-end to form a joint with good contact between the members. The fasteners were pressed into the members using the Shimadzu Universal Testing Machine in the laboratory at the Department of Forestry, Australian National University. The fasteners were pressed simultaneously, one on each side of the joint. Care was taken to ensure that the plate on the fastener on the lower side of the joint was flush with the timber face leaving a clearance between the timber and the plate on one side of the upper half of the joint. The clearance equalled the difference in thickness of the two members as shown in Figure 2.1.

Particular attention in the pressing of the fasteners was necessary to avoid bending the extreme end of the upper plate over the thinner member. Bending of the plate would increase the teeth penetration and offset the clearance formed due to the difference in thickness between the two members.

Certain provisions of Australian Standard 1649-1974 which specify the standard procedures for the calculation of basic working loads of metal connectors, were not followed as a matter of convenience in the tests carried out for this study as it was not intended to calculate basic working loads but rather compare loads.

In the Australian Standard it is required that normal fabrication methods be used in the preparation of the specimens. In this study the joints were pressed in a Shimadzu Universal Testing Machine. The pressing was 3 mm per minute for the preliminary testing programme and 10 mm per minute for the subsequent joints. The speed of pressing was increased to reduce the time required to prepare the joints. A joint ready for pressing is shown in Plate 2.2.

The pressing method was adopted to provide control over the pressing of the plates, thus avoiding any unnecessary penetration of the nails and crushing of the timber, and to enable the joints to be pressed without using the presses of the truss fabricators as the time required would not have been acceptable to them.

The joints fabricated using Karri and Alpine Ash were pressed in the green condition and the joints fabricated with Radiata Pine were

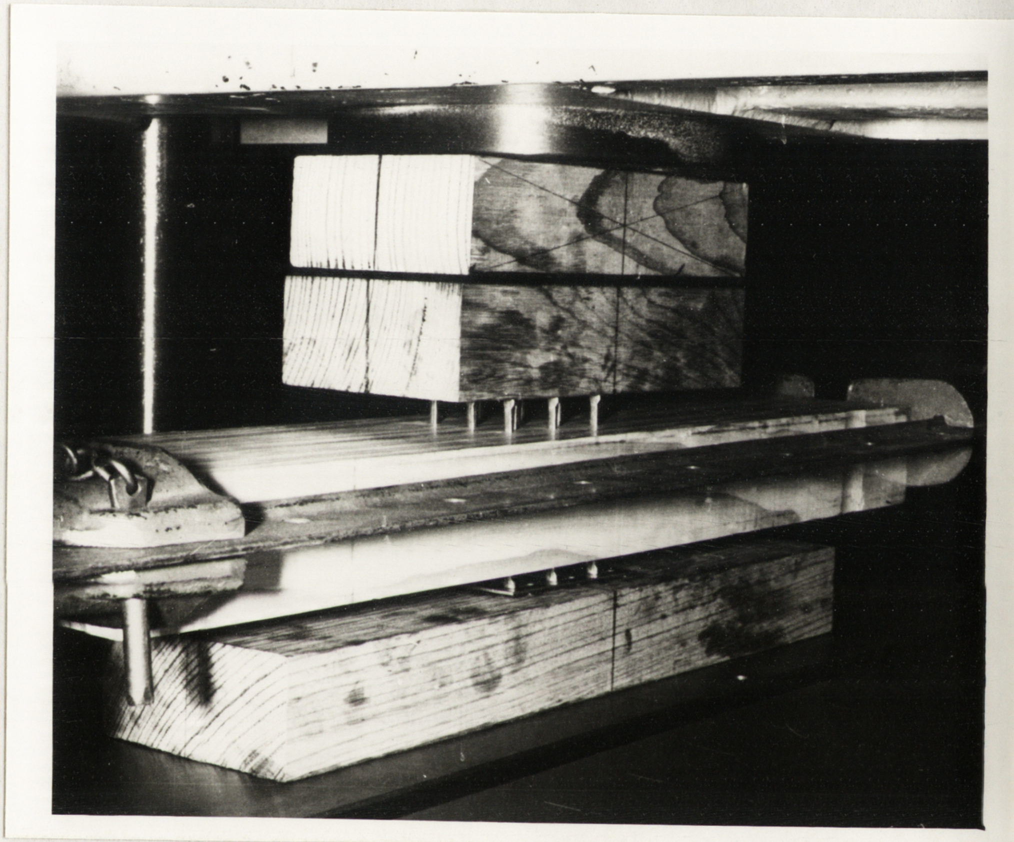


PLATE 2.2
Pressing of joints.

pressed in the dry condition. To ensure that the timber was in a green condition at the time of pressing check readings of moisture content were taken with a resistance-type electrical moisture meter, Model DCR 9-T, prior to dressing to size and the green dressed material was stored in polythene sheets and bags until they were pressed. The penetration load and the maximum pressing loads were recorded. The penetration load was assumed to be the load at which the entire length of the nail had penetrated the timber, the maximum pressed load was recorded as the load when the plates were well in contact with the timber.

After pressing, four 1.59 cm (5/8") diameter holes were drilled, two in each end of the specimen, to take the bolts through which the known loads would be applied, see Plate 2.1. The distance of the holes from the end of the timber was calculated to ensure that failure of timber in shear did not occur between the bolt holes and the end of the timber. The bolt holes were 10.16 cm (4") to 12.70 cm (5") away from the ends of the timber and 6.35 cm (2½") apart and equidistant from each edge of the member.

The joints fabricated with Karri and Alpine Ash and to be tested in the dry condition were stored in a shed with one side open for six weeks until the moisture content was about 20% and then stored in a conditioning room till an evenly distributed moisture content of 12 - 15% was obtained. The conditioning room was maintained at a temperature of 20 ± 2 °C and a relative humidity of 65%. The total period of seasoning ranged from three to four months. Both in the open air in the shed and the conditioning room the joints were stacked in such a way as to ensure that a free flow of air could occur over all faces and ends of the test specimens.

After conditioning to approximately 12% moisture content some clearances between the plate and the timber were measured with a depth micrometer to assess the effect of shrinkage of the timber on the clearances between the timber and the plate. These measurements are discussed in Chapter IV.

2.2.5 Testing the Joints

All joints were tested in the Shimadzu REH30 Universal Testing Machine. A special attachment was developed for the test and is shown in Plate 2.3. The load was transferred from the cross heads of the testing machines to the test specimen through a crossarm and steel strips to four bolts passing through the specimen. The crossarm ensured that equal loads were transferred to each bolt even with some eccentricity at the joint.

The load was applied continuously to the specimen during the test to failure at a rate of 2.50 mm per minute. The rate of testing was adopted to reduce the testing time at the time of the preliminary series of tests. Australian Standard AS 1649-1974 published after the preliminary series of tests specifies a loading of 1.25 mm per minute. It was decided to retain the loading rate of 2.50 mm per minute throughout the series of tests to ensure comparability of all test results.

Measurements of the actual deflections at the joints would have required reading of dial gauges of an extensometer attached to the specimen but this was not possible as the testing had to be carried out by one observer. Load-deflection diagrams were recorded on the testing machine but the deflection recorded was the movement of the cross head of the testing machine and this included deflection of the strips. This was proportional to the load.

Moisture contents of the specimens were verified soon after the test.

2.2.6 Data Processing

Data from the tests were punched on to computer cards and correlation and regression analysis was done in the CYBER 76 computer at the Division of Computing Research at the Commonwealth Scientific and Industrial Research Organization in Canberra.

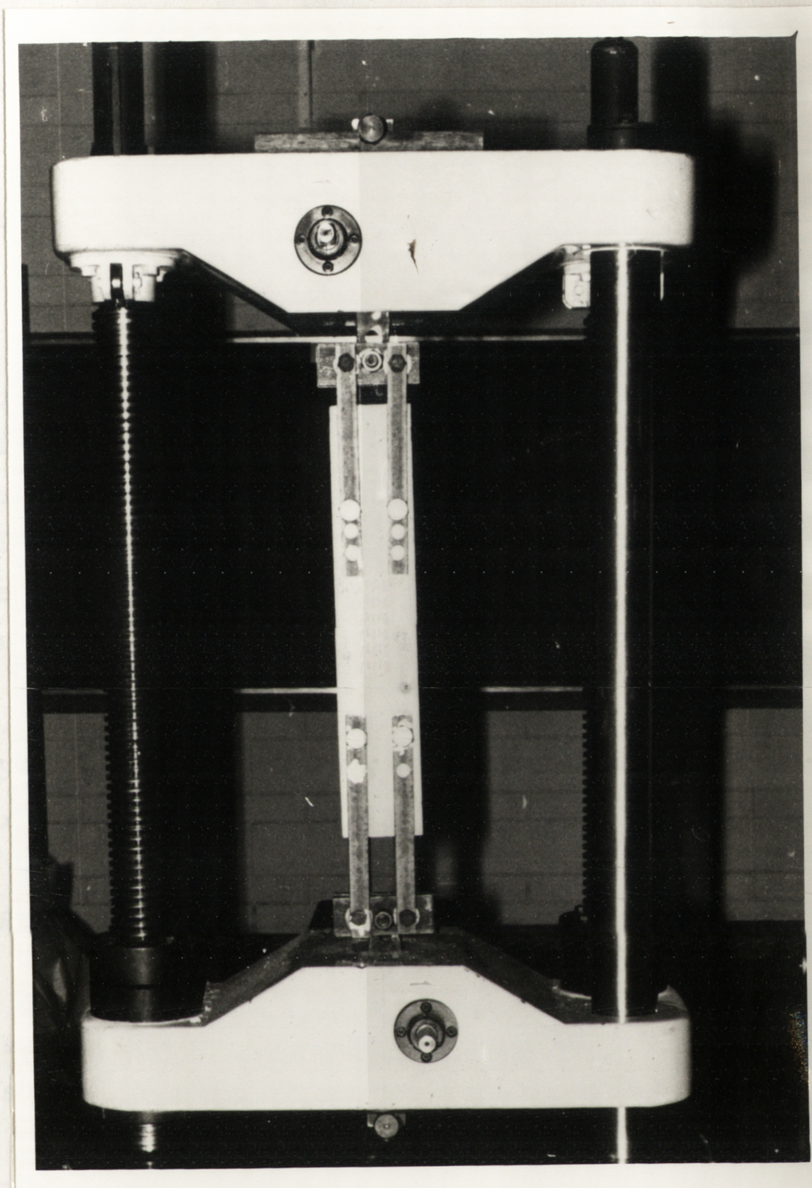


PLATE 2.3

Tension testing of joints.

2.3 RESULTS AND DISCUSSION

2.3.1 Pressing Loads

Pressing loads were recorded at the time of fabrication of the test specimens.

In pressing fasteners into timber members with different thickness the plates were pressed right into the timber on three quarters of the plate area as illustrated in Figure 2.1. It was expected therefore that the magnitude of the pressing load would not change substantially with changes in the difference in thickness of the timber. This was confirmed by analysis of the data. Maximum pressing loads were not significantly correlated with differences in thickness of the timber members within each of the three species.

The statistical analysis of the pressing loads is shown in Tables 2.5.1, 2.5.2 and 2.5.3. Only one set of ten in Radiata Pine, one set in six in Karri and one set in four in Alpine Ash showed differences at the 5% significance level. That is there were no very significant or highly significant differences between sets in respect of pressing loads.

It was accepted therefore that any small variation in pressing loads, as a result of differences in thickness of the members, would not be a significant factor in the behaviour of the joint.

The magnitude of the load to press the plates flush to the timber is significantly related to the species. The analysis of the pressing loads for four types of plates in the three timber species is given in Table 2.6.

In general Alpine Ash required the highest pressing load followed by Karri and Radiata Pine. Alpine Ash is in a lower strength and joint group and has a lower density than Karri and in this respect the relative magnitude of the pressing loads for Alpine Ash and Karri are anomalous. The specific mechanical properties and the basic density of the three species are tabulated in Table 2.7.

The type of plate also has a marked influence on the pressing load. In Tables 2.5 the variance ratios of the pressing loads between

TABLE 2.5.1

Statistical analysis of relation between difference in timber thickness and maximum pressing loads and plate types.

Radiata Pine

SET	TIMBER GRADE	PLATE TYPE	PRESSING LOAD[1]		CORRELATION[2]		DEGREES OF FREEDOM	F	V_1 & V_2
			Mean	Standard Deviation	Coefficient	Level of Significance			
1	1600f	Gangnail I	26250	3570	-0.1970	Not Significant	32		
2	1250f	"	25900	4900	-0.4900	N.S.	14		
3	1000f	"	23760	2780	-0.6540	*(0.05)	11		
4	800f	"	24240	4280	-0.0722	N.S.	11		
5	Reject	"	22880	2760	-0.3010	N.S.	9		
6	1250f	Gangnail II	32240	5270	-0.3780	N.S.	12	161.940 Highly significant	9,143
7	1250f	Steelfast I	35250	2920	-0.2330	N.S.	13		
8	1250f	Steelfast II	40360	5340	-0.0626	N.S.	13		
9	1250f	Sanford I	65100	7490	-0.0663	N.S.	9		
10	1250f	Sanford II	84100	13680	-0.3390	N.S.	9		

1) Newtons.

2) Simple linear correlation between pressing load and difference in thickness.

TABLE 2.5.2

Statistical analysis of relation between difference in timber thickness and maximum pressing loads and plate types.

Alpine Ash

SET	PLATE TYPE	PRESSING LOAD[1]		CORRELATION[2]		DEGREES OF FREEDOM	F	V_1 & V_2
		Mean	Standard Deviation	Coefficient	Level of Significance			
1	Gangnail I	38870	3500	-0.050	Not Significant	12		
2	"	38600	4690	-0.348	N.S.	12		
3	Gangnail II	38680	2910	-0.227	N.S.	10		
4	"	38340	2690	-0.579	*(0.05)	12	91.45	7,106
5	Steelfast I	42090	4180	-0.526	*(0.05)	13	***	
6	"	43380	2480	-0.156	N.S.	13		
7	Steelfast II	58660	6100	-0.590	*(0.05)	13		
8	"	62400	2960	-0.299	N.S.	13		
9	Sanford I	76660[3]	7890	-0.495	N.S.	8		
10	"	84520[3]	3600	-0.153	N.S.	8		
11	Sanford II	111060[3]	8770	-0.785	*(0.05)	8	29.42	3,28
12	"	110540[3]	13790	-0.319	N.S.	8	***	

1) Newtons.

2) Simple linear correlation between pressing load and difference in thickness.

3) Two plates pressed simultaneously.

TABLE 2.5.3

Statistical analysis of relation between difference in timber thickness and maximum pressing loads and plate types.

Karri

SET	PLATE TYPE	PRESSING LOAD[1)]		CORRELATION[2)]		DEGREES OF FREEDOM	F	V_1 & V_2
		Mean	Standard Deviation	Coefficient	Level of Significance			
1	Gangnail I	41600	3560	-0.443	Not Significant	12		
2	"	41410	2500	-0.111	N.S.	12		
3	Gangnail II	37780	2850	-0.160	N.S.	12		
4	"	36530	3180	-0.120	N.S.	12	30.77	5,79
5	Steelfast II	48290	4780	-0.689	*(0.05)	13	***	
6	"	50050	4760	-0.274	N.S.	12		

1) Newtons.

2) Simple correlation between pressing load and difference in thickness.

TABLE 2.6

Comparison of maximum pressing load for different species.

TYPE OF PLATE	MAXIMUM PRESSING LOADS (Newtons) RADIATA PINE		ALPINE ASH		KARRI		V_1 & V_2	F	SIGNIFICANCE LEVEL
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation			
Gangnail I	25900	4900	38870	3500	41600	3560	2,41	64.32	***
Gangnail II	32240	5270	38680	2910	37780	2850	2,37	8.79	***
Steelfast I	35250	2900	42090	4180	...1)	...	1,28	26.96	***
Steelfast II	40360	5340	58660	6100	48290	4780	2,42	42.84	***

1) Test specimens not fabricated.

TABLE 2.7

Mechanical properties of test species.

SPECIES	COMPRESSION PERPENDICULAR TO GRAIN[1] Megapascals		CLEAVAGE Newtons/cm		HARDNESS Newtons		DENSITY gm/cc
	Radial	Tangential	Radial	Tangential	Janka	Hardness Value	
Radiata Pine (12%)	5.82	5.43	462	524	3270	3430	0.507[2]
Alpine Ash (Green)	4.74	5.88	496	604	4090	3940	0.537[3]
Karri (Green)	6.59	8.68	641	806	6230	5870	0.696

Source: The Mechanical Properties of 174 Australian Timbers. Division of Forest Products Technological Paper No. 25. C.S.I.R.O. Australia 1963.

1) Stress at limit of proportionality based on 6" × 2" × 2" specimen.

2) Air dry.

3) Basic.

different types of plates in different sets are highly significant. This is of course due to the difference in length, thickness, shape and number of teeth in the plates.

Five different grades of Radiata Pine, namely 1600f, 1250f, 1000f, 800f and reject were pressed with the same type and size of plates. The analysis of these results is also shown in Table 2.5.1 and there is no significant effect of the timber grade on the pressing loads. This is probably a result of the selection of clear material out of the various stress grades for the fabrication of the joints, whereas the actual stress grade of Radiata Pine is to a large extent determined by the defect.

2.3.2 Ultimate Loads

In the series of tests reported in this study the ultimate load is taken as the measure of the strength of the joint and comparisons between joints are on the basis of that load. AS 1649-1974 specifies two loads as measures of the basic working loads of metal fasteners, the ultimate load and the load at a deflection of 0.8 mm. The measurement of the load at a deflection of 0.8 mm would have required at least one additional operator during testing of the joints and this was not feasible in this project.

PART A
Initial Tests on Radiata Pine

Tests on joints fabricated with five different stress grades of Radiata Pine but with the same type of fastener and with differences in the thickness of the timber members, were undertaken to determine:

(a) if the stress grade of the timber influenced the ultimate load;

(b) the magnitude of the reduction in the ultimate load as a result of differences in thickness of the members;

(c) the variability in the ultimate loads to assess the number of joints that should be fabricated in each test series;

FIGURE 2.2

Regression lines for five grades of Radiata Pine.
Ultimate load v. difference in thickness.

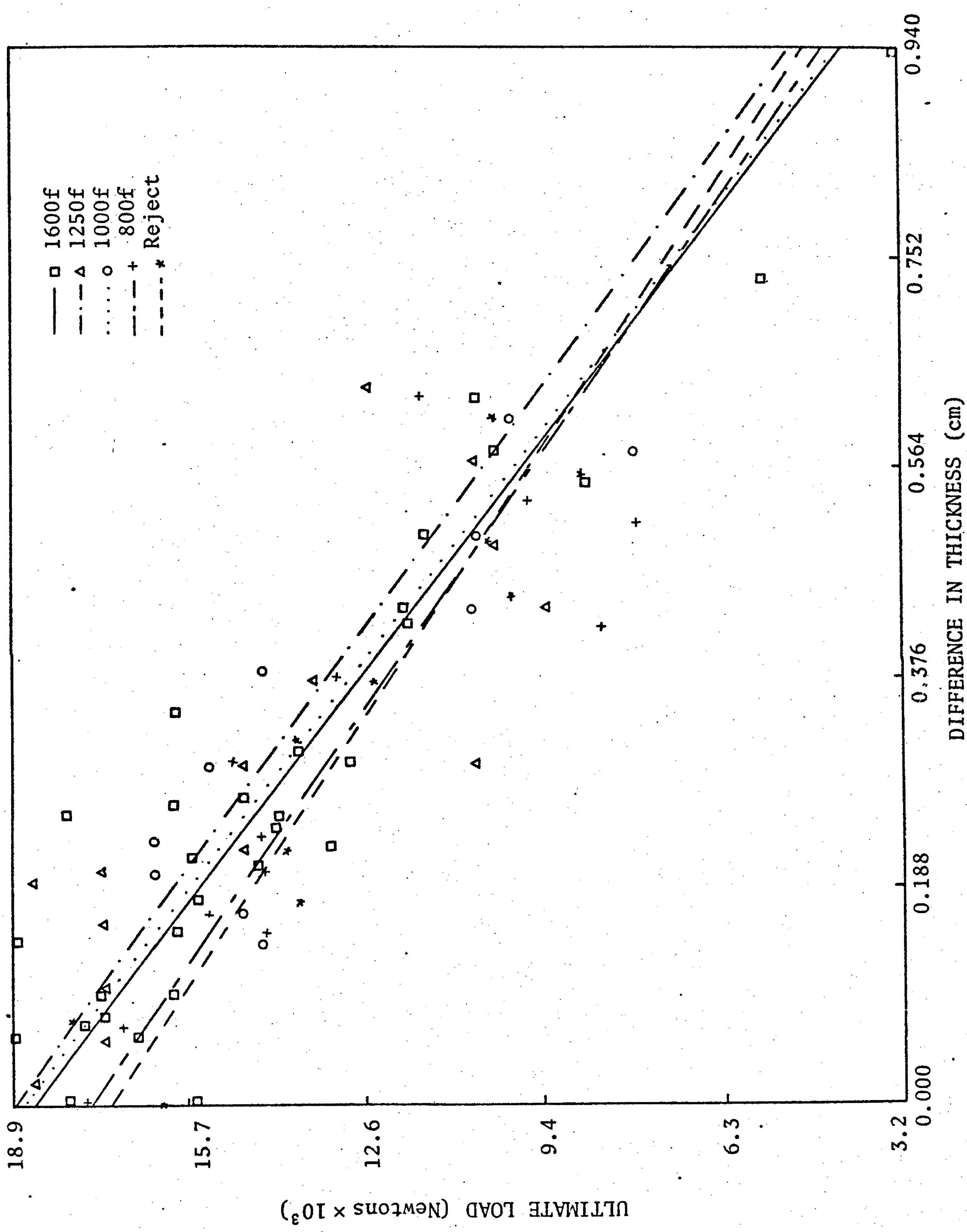


TABLE 2.8

Statistical analysis of test results on five grades of Radiata Pine fasteners: Gangnail Type I.

TIMBER GRADE	NUMBER OF JOINTS	ULTIMATE LOADS Mean (Newtons)	Standard Deviation	Correlation Coefficient 1)	Variance 2) Ratio & V_1/V_2	SLOPE 3)	STANDARD ERROR OF SLOPE	INTERCEPT (Newtons)	STANDARD ERROR OF INTERCEPTS
1600f	32	14180	3690	-0.927***		-15,100	1,130	18,560	415
1250f	14	14680	3240	-0.829***		-14,600	2,720	18,860	920
1000f	11	13250	2880	-0.890***	0.65 (NS)	-15,400	2,600	18,674	1015
800f	11	13500	3150	-0.868***		-13,900	2,400	17,470	820
Reject	9	12900	2940	-0.940***	4/75	-13,380	1,720	17,270	660
(Total)	77	13870	3300	-0.893		-14,710	838	18,300	303

1) Correlation coefficient between ultimate load and difference in thickness of timber members and significance level

*** Highly significant
NS Not significant.

2) V_1 and V_2 are the degrees of freedom for between and within sets.

3) Newtons per cm difference in thickness of members.

(d) the range in the difference in thickness of the joint.

The stress grades used were 1600f, 1250f, 1000f, 800f and "reject". Gangnail Type I connectors were used to fabricate the joints.

The results of this series of tests is shown in Figure 2.2 and the analysis of the results is presented in Table 2.8.

There is a highly significant relation between the ultimate loads and the difference in thickness between members for all grades of Radiata Pine.

A chi-square value of 1,684 with four degrees of freedom indicates that the correlation coefficients are homogeneous and the coefficient of 0.893 for all grades can be taken as a common coefficient.

The variance ratio of 0.65 with degrees of freedom of four and seventy five indicates that the mean ultimate loads are not significantly different and thus independent of grade.

Table 2.8 also indicates that the slopes and intercepts do not differ substantially between the timber grades. Further tests for homogeneity of the regression lines were therefore undertaken and the results are shown in Table 2.9.

TABLE 2.9

Statistical tests of homogeneity of regression lines.

TEST: SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	VARIANCE RATIO
Parallelism				
Common Slope	1	674.219	674.219	297.03
Between Slopes	4	1.366	0.342	0.15
Identity				
Common Line	2	16073.437	8036.718	
Regression Lines	8	15.704	1.963	0.86 NS
Residual	70	158.892	2.269	

There is a significant difference between common and individual slopes but the individual slopes are not significantly different between themselves. The analysis of covariance in testing for equal intercepts also produced an insignificant variance ratio of 1.66 with four and seventy four degrees of freedom.

The justification of assuming linearity of regression lines was checked by means of a quadratic regression analysis. Table 2.10 shows the variance ratios of additional reduction on residual mean squares by quadratic fitting and the respective coefficients. The additional reduction gained over linear fitting by quadratic fitting was not great except in the first set of 1600f grade.

TABLE 2.10

Initial tests of Radiata Pine
variance ratios and quadratic coefficients.

SET	V_1, V_2	VARIANCE RATIO	B_0	B_1	B_2
1 (1600f)	1,28	4.34	17,772	-8,716	-7,926
2 (1250f)	1,12	1.04 NS	19,998	-24,772	15,660
3 (1000f)	1,8	3,03 NS	14,697	10,172	-33,828
4 (800f)	1,10	0.92 NS	18,317	-22,418	13,517
5 (Reject)	1,7	0.01 NS	17,342	-14,126	1,211

The inconsistency in the signs of the B_2 coefficients in the quadratic analysis favours the choice of simple linear analysis in which the coefficients are consistent and the correlation coefficients are highly significant.

It was concluded that the analysis and interpretation of the results in linear form is justified.

Conclusions

1. The initial experiment showed that there was no significant relation between ultimate loads and stress grade of the

* Examiners drew attention to this - the significance not stated explicitly. Assume is significant but level not known

DDS 7/12/77

Radiata Pine. It is concluded therefore that in terms of joint design grade separation of Radiata Pine is not justified if the fabrication of the timber is such that clear wood occurs at all joints. Radiata Pine of quality 1250f was chosen for further testing and comparison with Karri and Alpine Ash as this material was readily available and confining the material selected to one grade rather than using a range of grades could assist subsequent interpretation of the results.

2. There is a highly significant linear relation between the ultimate loads and the difference in thickness between members at joints.

3. The analysis and interpretation of results in linear form is justified.

PART B

Testing Programme to Determine the Effect of Differences in Timber Thickness on the Strength of Timber Joints Made with Metal Fasteners

Results

The results of the testing programmes summarized in Tables 2.3 are shown in Figures 2.3. The statistical analysis of the results is presented in Tables 2.11.

Analysis of Results

In all the sets tested there is a highly significant linear correlation between the ultimate strength of the joint and the difference in thickness between the members.

The variance ratio of the original mean square to the additional reduction gained by quadratic regression and their significance levels are given in Column (9) of Table 2.11.1 and Column (13) of Tables 2.11.2 and 2.11.3. The quadratic regression fittings for the test results didnot significantly improve the simple linear regression except for the Sanford Plate in Radiata pine and karri.

FIGURE 2.3.1

Regression lines for five fasteners in Radiata Pine.
Ultimate load v. difference in thickness.

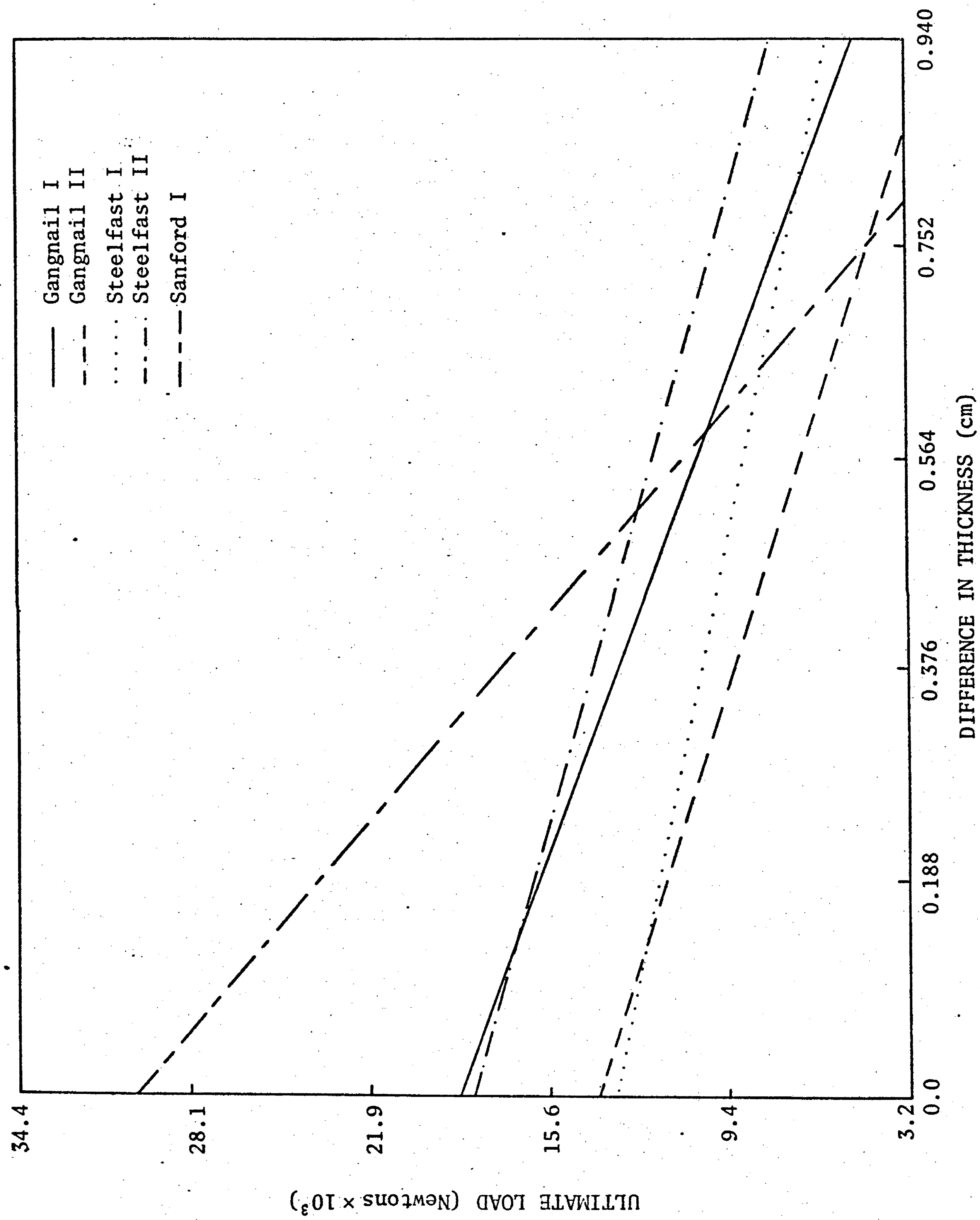


FIGURE 2.3.2

Regression lines for five fasteners in green Alpine Ash.
Ultimate load v. difference in thickness.

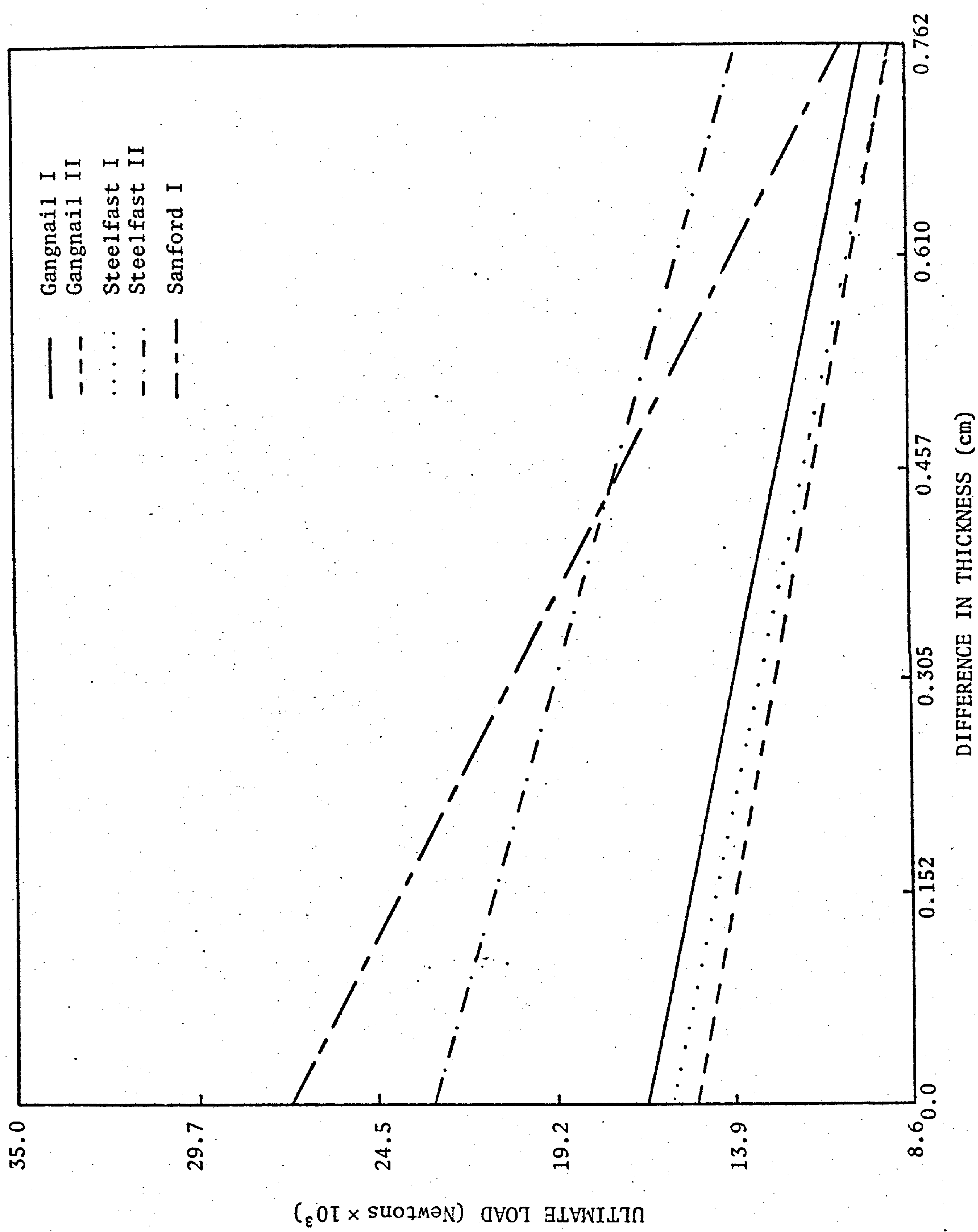


FIGURE 2.3.3

Regression lines for four fasteners in dried Ash.
Ultimate load v. difference in thickness.

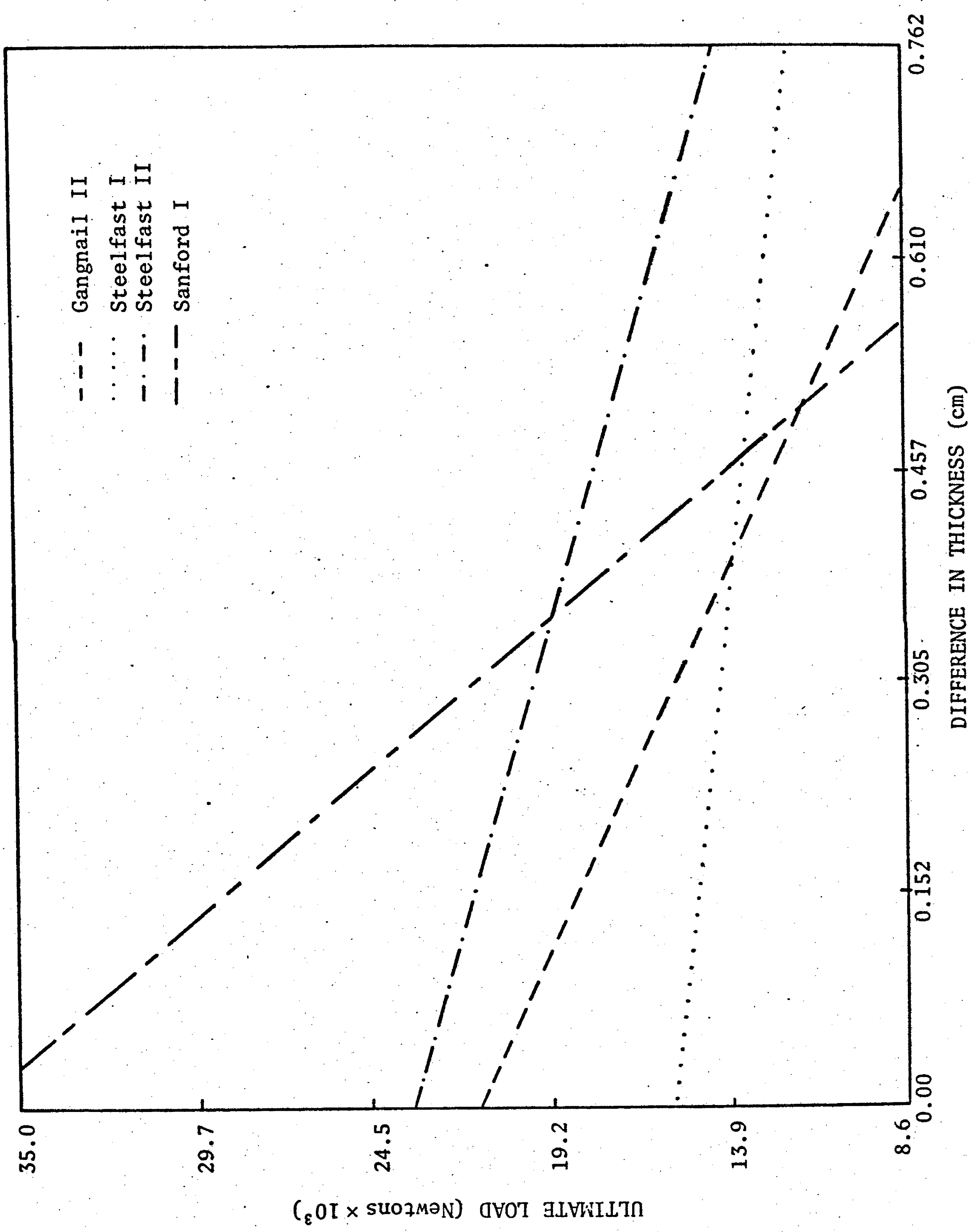


FIGURE 2.3.4

Regression lines for five fasteners in Alpine Ash.
Ultimate load v. difference in thickness.

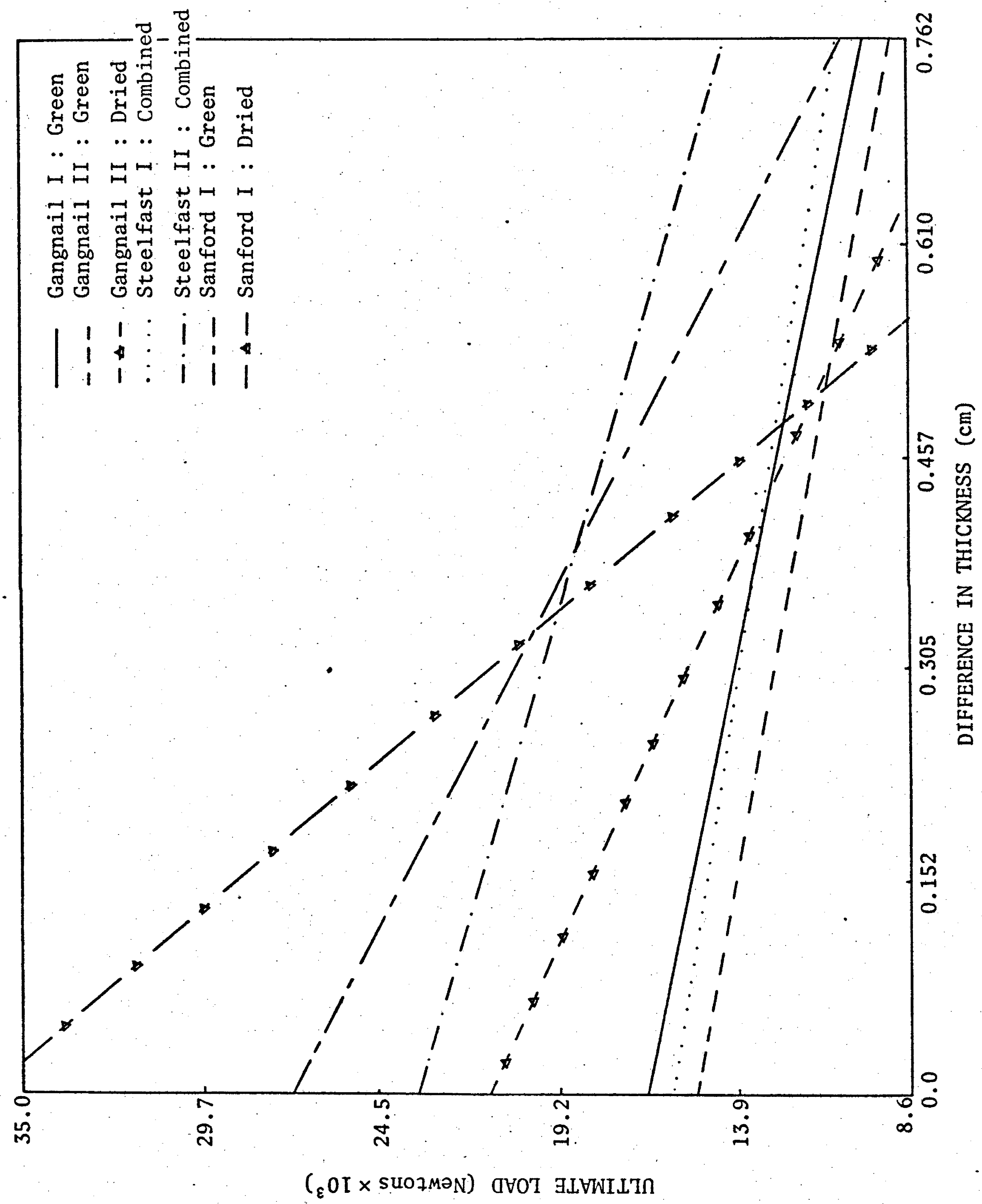


FIGURE 2.3.5

Regression lines for four fasteners in green Karri.
Ultimate load v. difference in thickness.

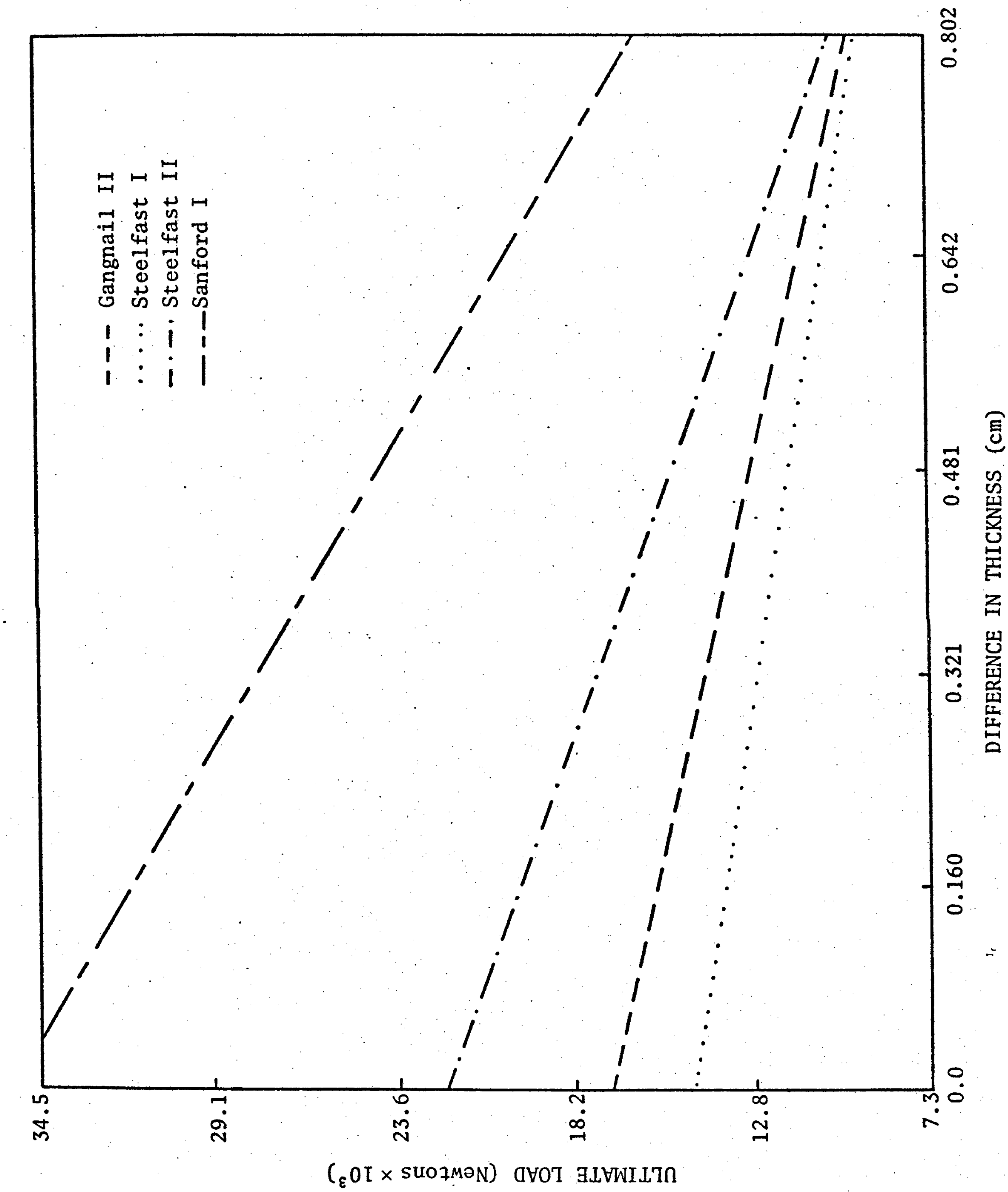


FIGURE 2.3.6

Regression lines for four fasteners in dried Karri.
Ultimate load v. difference in thickness.

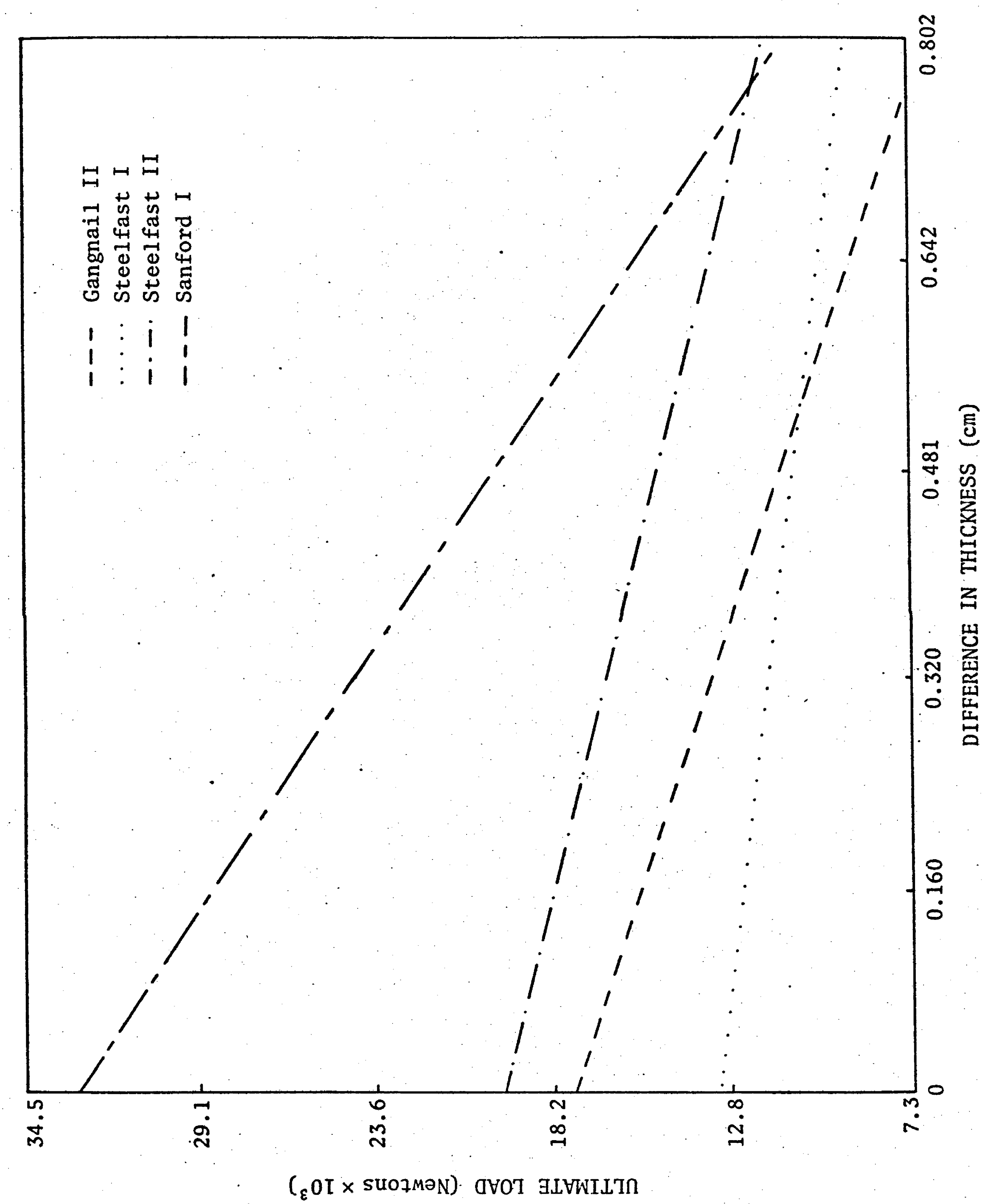


FIGURE 2.3.7

Regression lines for four fasteners in Karri.
(Common lines for Green and Dried.)
Ultimate load v. difference in thickness.

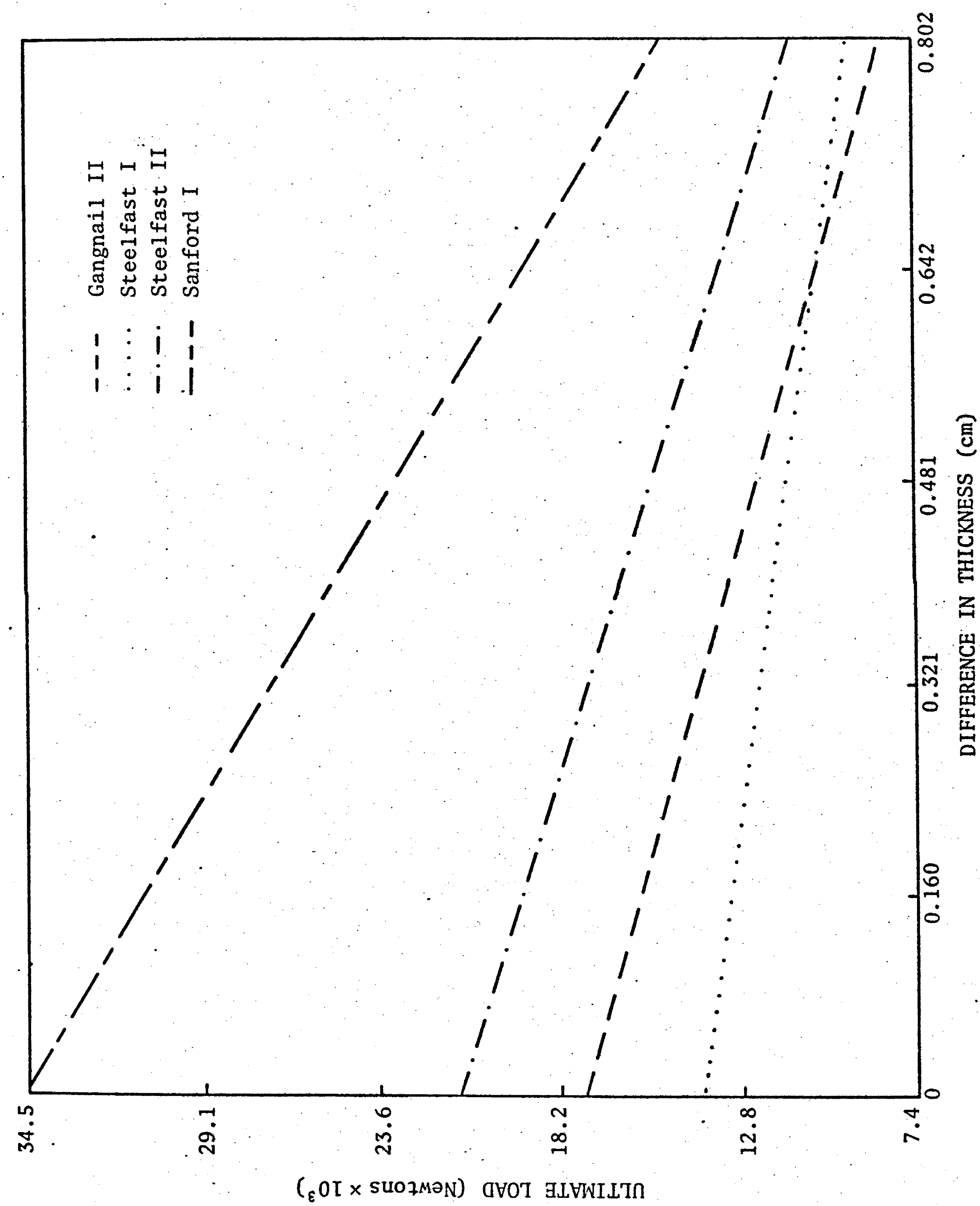


TABLE 2.11.1

Statistical analysis of results of joint tests.
Regression of ultimate load on difference in thickness.

Radiata Pine

TYPE OF PLATE (1)	CORRELATION COEFFICIENT[1)] (2)	MEAN ULTIMATE LOAD Newtons (3)	STANDARD ERROR OF LOAD (4)	SLOPE Newtons per cm (5)	STANDARD ERROR OF SLOPE (6)	INTERCEPT Newtons (7)	STANDARD ERROR OF INTERCEPT (8)	QUADRATIC VARIANCE RATIO[2)] (9)
Gangnail I	-0.829***	14700	3200	-14600	2700	18900	920	1.06 N.S.
Gangnail II	-0.893***	11500	3000	-12400	1800	14100	530	4.75 N.S.
Steelfast I	-0.876***	11600	2400	-8200	1200	13600	430	0.11 N.S.
Steelfast II	-0.761***	15800	3700	-11000	2600	18500	900	4.48 N.S.
Sanford I	-0.854***	23600	7400	-33400	8300	30400	2200	21.56***

1) Linear correlation coefficient between difference in thickness and ultimate load.
Significance levels

* = 0.05
** = 0.01
*** = 0.001
N.S. = Not significant.

2) Variance ratio to test the reduction in variance by quadratic regression lines.

TABLE 2.11.2

Statistical analysis of results of joint tests.
Regression of ultimate load on difference in thickness.

Karri

TYPE OF PLATE (1)	MOISTURE CONDITION (2)	CORRELATION COEFFICIENT[1)] (3)	MEAN ULTIMATE LOAD Newtons (4)	STANDARD ERROR OF LOAD (5)	VARIANCE RATIO[3)] (Load) (6)
Gangnail II	Green	-0.64*	15200	3050	0.04 N.S.
	Dry	-0.63*	14900	4600	(1,26)
	Combined[2)]	-0.62***	15000	3800	
Steelfast I	Green	-0.76***	12900	1900	2.56 N.S.
	Dry	-0.59***	12000	2000	(1,56)
	Combined[2)]	-0.66***	12400	2000	
Steelfast II	Green	-0.83***	18500	4500	0.65 N.S.
	Dry	-0.74***	17300	3500	(1,27)
	Combined[2)]	-0.78***	17900	4000	
Sanford I	Green	-0.83***	27900	5400	0.29 N.S.
	Dry	-0.94***	26300	5100	(1,11)
	Combined[2)]	-0.82***	27100	5100	

1) Linear correlation coefficient between difference in thickness and ultimate load.
Significance levels: * = 0.05; ** = 0.01; *** = 0.001; N.S. = Not significant.

2) Data for green and dry moisture conditions combined.

3) Variance ratio and degrees of freedom to test difference between green and dry joints.

TABLE 2.11.2 (cont'd)

Karri

TYPE OF PLATE (1)	MOISTURE CONDITION (2)	SLOPE Newtons per cm (7)	STANDARD ERROR OF SLOPE (8)	VARIANCE RATIO[3] (Slope) (9)	INTERCEPT Newtons (10)	STANDARD ERROR OF INTERCEPT (11)	VARIANCE RATIO[3] (Intercept) (12)	QUADRATIC VARIANCE RATIO[3] (13)
Gangnail II	Green	- 8900	3100	0.59 N.S.	17000	900	0.07 N.S.	0.55 N.S.
	Dry	-13200	4700	(1,24)	17600	1400	(1,25)	3.42 N.S.
	Combined[2]	-11100	3700		17300	800		3.89 N.S.
Steelfast I	Green	- 6100	1000	0.47 N.S.	14500	400	4.33*	1.34 N.S.
	Dry	- 5000	1300	(1,54)	13400	500	(1,55)	0.52 N.S.
	Combined[2]	- 5600	850		14000	300		1.76 N.S.
Steelfast II	Green	-14700	2700	1.36 N.S.	22100	900	1.10 N.S.	0.00 N.S.
	Dry	-10200	2700	(1,25)	20000	970	(1,26)	0.34 N.S.
	Combined[2]	-12600	1900		21100	700		0.13 N.S.
Sanford I	Green	-23800	7200	0.13 N.S.	35300	2600	4.50 N.S.	0.01 N.S.
	Dry	-27200	5200	(1,9)	33000	1500	(1,11)	21.45***
	Combined[2]	-23500	5000		33800	1600		1.10 N.S.

1) Linear correlation coefficient between difference in thickness and ultimate load. Significance levels: * = 0.05; ** = 0.01; *** = 0.001; N.S. = Not significant.

2) Data for green and dry moisture conditions combined.

3) Variance ratio and degrees of freedom to test difference between green and dry joints.

4) Variance ratio to test the reduction by quadratic regression lines as compared to linear.

TABLE 2.11.3

Statistical analysis of results of joint tests.
Regression of ultimate load on difference in thickness.

Alpine Ash

TYPE OF PLATE (1)	MOISTURE CONDITION (2)	CORRELATION COEFFICIENT[1] (3)	MEAN ULTIMATE LOAD Newtons (4)	STANDARD ERROR OF LOAD (5)	VARIANCE RATIO[3] (Load) (6)
Gangnail I	Green	-0.836***	14400	2500	
Gangnail II	Green	-0.614*	13200	2800	6.68*
	Dry	-0.857***	17300	4800	(1,24)
Steelfast I	Green	-0.841***	13600	2600	1.00 N.S.
	Dry	-0.610*	14500	2100	(1,28)
	Combined[2]	-0.721***	14100	2300	
Steelfast II	Green	-0.870***	20000	3500	0.16 N.S.
	Dry	-0.806***	20500	3700	(1,28)
	Combined[2]	-0.834***	20200	3600	
Sanford I	Green	-0.719*	23100	5500	0.30 N.S.
	Dry	-0.976***	25200	9500	(1,12)

1) Linear correlation coefficient between difference in thickness and ultimate load. Significance levels: * = 0.05; ** = 0.01; *** = 0.001; N.S. = Not significant.

2) Data for green and dry moisture conditions combined.

3) Variance ratio and degrees of freedom to test difference between green and dry joints.

TABLE 2.11.3 (cont'd)

Alpine Ash

TYPE OF PLATE (1)	MOISTURE CONDITION (2)	SLOPE Newtons per cm (7)	STANDARD ERROR OF SLOPE (8)	VARIANCE RATIO[3] (Slope) (9)	INTERCEPT Newtons (10)	STANDARD ERROR OF INTERCEPT (11)	VARIANCE RATIO[3] (Intercept) (12)	QUADRATIC VARIANCE RATIO[3] (13)
Gangnail I	Green	- 8500	2100		16600	700		
Gangnail II	Green	- 7500	3100	6.37*	15000	1000	12.2***	0.65 N.S.
	Dry	-19000	3300	(1,22)	21300	1000	(1,23)	0.41 N.S.
Steelfast I	Green	- 8600	1500	2.32 N.S.	15700	500	2.10 N.S.	0.16 N.S.
	Dry	- 5000	1800	(1,26)	15700	600	(1,27)	0.94 N.S.
	Combined[2]	- 6800	1200		15700	400		0.92 N.S.
Steelfast II	Green	-11900	1900	0.00 N.S.	22900	700	0.53 N.S.	0.03 N.S.
	Dry	-11800	2400	(1,26)	23400	800	(1,27)	0.05 N.S.
	Combined[2]	-11900	1500		23100	500		0.09 N.S.
Sanford I	Green	-21600	8500	6.03*	27200	2200	2.45 N.S.	0.06 N.S.
	Dry	-48400	5300	(1,10)	36500	1500	(1,12)	0.06 N.S.

1) Linear correlation coefficient between difference in thickness and ultimate load. Significante levels: * = 0.05; ** = 0.01; *** = 0.001; N.S. = Not significant.

2) Data for green and dry moisture conditions combined.

3) Variance ratio and degrees of freedom to test difference between green and dry joints.

4) Variance ratio to test the reduction by quadratic regression lines as compared to linear.

The ultimate load and intercepts of air dried joints are higher than for green joints for all types of plates in the case of Alpine Ash. On the other hand the effect of drying is opposite to this in the case of Karri, that is joints tested in the green condition are stronger than air dried joints.

Columns (9) and (12) of Tables 2.11.2 and 2.11.3 test the identity of the regression lines and their significance levels between green and dried joints. The analysis shows that:

(a) the joints fabricated in Karri show no significant difference between the regression lines except for Steelfast I plates. The combined common lines are given right after the green and dry data.

(b) for the joints fabricated in Alpine Ash the regression lines for the green and dry joints are significantly different except in the case of the Steelfast plates.

The intercepts shown in Column (10) of Tables 2.11.2 and 2.11.3 represent the value of the ultimate strength of a joint with zero difference in thickness based on the tests undertaken. A more meaningful comparison of the ultimate loads for each type of fastener is obtained by converting the values shown in Column (10) to values for the same area of fastener. These values are shown in Table 2.12 in which the Sanford fasteners are taken as the datum and the values of the intercept for the other fasteners are adjusted to represent values for the same area of fastener as the Sanford fastener.

The fasteners rank consistently in each of the three species of timber and, in terms of load-carrying capacity per unit area of plate, as follows: Gangnail I, Gangnail II, Steelfast I, Steelfast II, Sanford I, in increasing order.

The slopes in Column (7) of Tables 2.11.2 and 2.11.3 show the reduction in ultimate strength in Newtons for a centimetre increase in difference in thickness between the members. A more meaningful and useful comparison between the types of fasteners and timbers investigated is shown in Table 2.13 which shows the percentage reduction in strength for every 2 mm increase in difference of thickness between the timber members.

TABLE 2.12

Comparison of ultimate loads of fasteners (on the basis of the area of the fastener).

TYPE OF FASTENER	ULTIMATE LOAD (Newtons)	
	Original[1)]	Adjusted[2)]
2.12.1 Radiata Pine		
Gangnail I	18,900	17,500
Gangnail II	14,100	18,600
Steelfast I	13,600	20,700
Steelfast II	18,500	27,600
Sanford I	30,400	30,400

TYPE OF FASTENER	ULTIMATE LOADS (Newtons)			
	Green		Dry	
	Original[3)]	Adjusted[2)]	Original[3)]	Adjusted[2)]
2.12.2 Karri				
Gangnail II	17,000	19,900	17,600	18,600
Steelfast I	14,500	22,100	13,400	20,700
Steelfast II	22,100	29,500	20,000	27,600
Sanford I	35,300	35,300	33,000	33,000
2.12.3 Alpine Ash				
Gangnail I	16,600	19,300	-	-
Gangnail II	15,000	20,600	21,300	15,300
Steelfast I	15,700	23,000	15,700	17,000
Steelfast II	22,900	30,500	23,400	22,700
Sanford I	27,200	27,200	36,500	36,500

1) Intercept: Column (7) Table 2.11.1.

2) Adjusted so that area of all fasteners equals that for the Sanford type.

3) Intercept: Column (10) Tables 2.11.2 and 2.11.3.

Table 2.13 raises a question as to whether or not there is any significant difference in the performance of each fastener between the three species of timber tested in regard to loss of strength as a consequence of a difference in thickness and a regression analysis between species was therefore undertaken. The results are shown in Table 2.14.

TABLE 2.13

Percentage reduction in strength for 2 mm increase in difference between two members.

TYPE OF FASTENER	MOISTURE CONDITION	PERCENTAGE REDUCTION IN STRENGTH Radiata Pine	Karri	Alpine Ash
Gangnail II	Green	-	10.5	10.0
	Dry	17.7	15.0	17.9
	Combined 1)	-	12.8	-
Steelfast I	Green	-	8.4	10.9
	Dry	12.0	7.4	6.3
	Combined 1)	-	8.0	8.6
Steelfast II	Green	-	13.3	10.4
	Dry	11.9	10.2	10.1
	Combined 1)	-	11.9	10.3
Sanford I	Green	-	13.5	15.9
	Dry	22.0	16.5	26.5
	Combined 1)	-	13.9	-

1) Results of green and dry combined where, as shown in Tables 2.11.2 and 2.11.3, there is no significant difference between green and dry.

Except for the dry specimens fabricated with Steelfast I fasteners there is no significant difference in the performance of each plate in the three species. The significant difference between species in the case of the Steelfast I fastener is probably due to the value obtained for this fastener in Radiata Pine for on testing it was found that there was no significant difference in the performance of this fastener between the dry Karri and Ash.

The testing programme to study the effects of difference in thickness of members on strength also provides a basis for comparison of the relative performance of the three species of timber used, viz.,

TABLE 2.14

Reduction in strength with difference in thickness.
Results of regression analysis between species.

TYPE OF PLATE	MOISTURE CONDITION	SLOPE[1] Newtons/cm Radiata Pine	Karri	Alpine Ash	Significance
Gangnail II	Green	-	- 8,900	- 7,500	NS
	Dry	-12,400	-13,200	-19,000	NS
Steelfast I	Green	-	- 6,100	- 8,600	NS
	Dry	- 8,200	- 5,000	- 5,000	
Steelfast II	Green	-	-14,700	-11,900	NS
	Dry	-11,000	-10,200	-11,800	NS
Sanford I	Green	-	-23,800	-21,600	NS
	Dry	-33,400	-27,200	-28,400	NS

1) Column (7) Tables 2.11.2 and 2.11.3.

Radiata Pine, Ash and Karri for there are test results for joints fabricated in each of these three species with one type of plate. The results of the statistical analysis to compare the relative performance of the three species is shown in Table 2.15.

The regression lines for Radiata Pine are the lowest for all the types of fasteners and there are significant differences in the mean ultimate loads and the intercepts, representing the ultimate load with zero difference in thickness, between the three species for each of the fasteners.

Between Karri and Alpine Ash the regression lines are higher in Alpine Ash than in Karri except in the case of the green specimens in Gangnail II and Sanford I fasteners. That is in general the Alpine Ash has a load-carrying capacity comparable with Karri in joints fabricated with metal fasteners. This is contrary to the relative load-carrying capacities as specified in AS 1720-1975. In that Code, Karri stands in a higher grade than Ash. Karri is J2 and Alpine Ash J3.

Stodart [personal communication] also found in a series of tests to determine the basic working loads of Sanford metal connectors that Ash was comparable to Karri. A summary of the results of that series is given in Appendix 2.1.

TABLE 2.15

Reduction in strength with difference in thickness.
Results of regression analysis between species.
(Continuing Table 2.14)

TYPE OF PLATE	MOISTURE CONDITION	INTERCEPTS[1] Newtons Radiata Pine	Karri	Alpine Ash	Significance
Gangnail II	Green	-	17,000	15,000	NS
	Dry	14,100	17,600	21,300	
Steelfast I	Green	-	14,500	15,700	NS
	Dry	13,600	13,400	15,700	
Steelfast II	Green	-	22,100	22,900	NS
	Dry	18,500	20,000	23,400	
Sanford I	Green	-	35,300	27,200	NS
	Dry	30,400	33,000	36,500	

1) Column (7) Table 2.11.1.
Column (10) Tables 2.11.2 and 2.11.3.

It is concluded therefore that the relative classification of Karri and ash for joint design purposes as given in AS 1720-1975 should be reviewed.

Summary of Findings

1. There is no substantial difference in the maximum pressing load to fabricate joints with difference in thickness between two members.

2. The type of plate has a very significant influence on the pressing loads.

3. The stress grade of Radiata Pine does not influence the maximum pressing load.

4. Alpine Ash requires a higher pressing load than Karri which in turn requires a higher pressing load than radiata pine when the

joints are fabricated with fasteners of the same type.

5. There is no significant difference between the ultimate loads of joints fabricated with various stress grades of Radiata Pine.

6. There is a highly significant linear relation between ultimate load and the difference in thickness between members of the joints with all types of plates and all species tested.

7. The load-carrying capacity is higher for dry than green Alpine Ash joints but lower for dry than green in the case of Karri.

8. Ash is comparable to Karri in terms of joint performance and the results suggest that Karri and Ash are not consistently classified in the Australian Standard AS1720-1975.

9. The reduction in strength associated with differences in thickness of the timber does not vary substantially with species but does depend on the type of plate.

CHAPTER III

VARIABILITY OF TIMBER THICKNESS

3.1 INTRODUCTION

The study described in Chapter II has established the magnitude of the reduction in strength of joints as a consequence of differences in thickness between the members for certain species and fasteners. The difference in the thickness of members at a joint is a chance event in that two pieces of timber are randomly matched and is determined mainly by the milling of the wood. The practical significance of the reduction in the strength of joints must therefore be assessed in relation to the probability of the occurrence of differences in thickness of members at a joint when the timber is either sawn or dressed.

The reductions in strength noted in Chapter II could be compensated by increasing the size of a fastener; that is in design terms, by reducing the allowable load per tooth. Thus the increased differences in thickness that could be expected to occur with sawn timber as compared to dressed could be allowed for in design. However it is common practice to use dressed timber for roof truss fabrication and by specification to limit the maximum difference in thickness between members to less than 2 mm, the maximum permitted difference allowed in the standard procedures for determining basic working loads of metal fasteners.

The studies to determine the probabilities of occurrence of various differences in thickness of members at joints fabricated with sawn and dressed timber are described in this chapter. The probabilities are then assessed in relation to the specification of sawn timber for timber roof trusses for there may be savings in using sawn timber with slightly larger plates relative to using dressed material.

3.2 VARIABILITY IN THICKNESS OF DRESSED TIMBER

The allowable tolerance in thickness for dressed hardwood is +0.4 mm in the Australian Timber Standards (see Table 1.2). The maximum difference in thickness of a timber joint fabricated with material meeting the Australian Standard should therefore be 0.4 mm. Nevertheless factory measurements, reported below, showed that differences in thickness greater than 0.4 mm occur in practice relatively frequently.

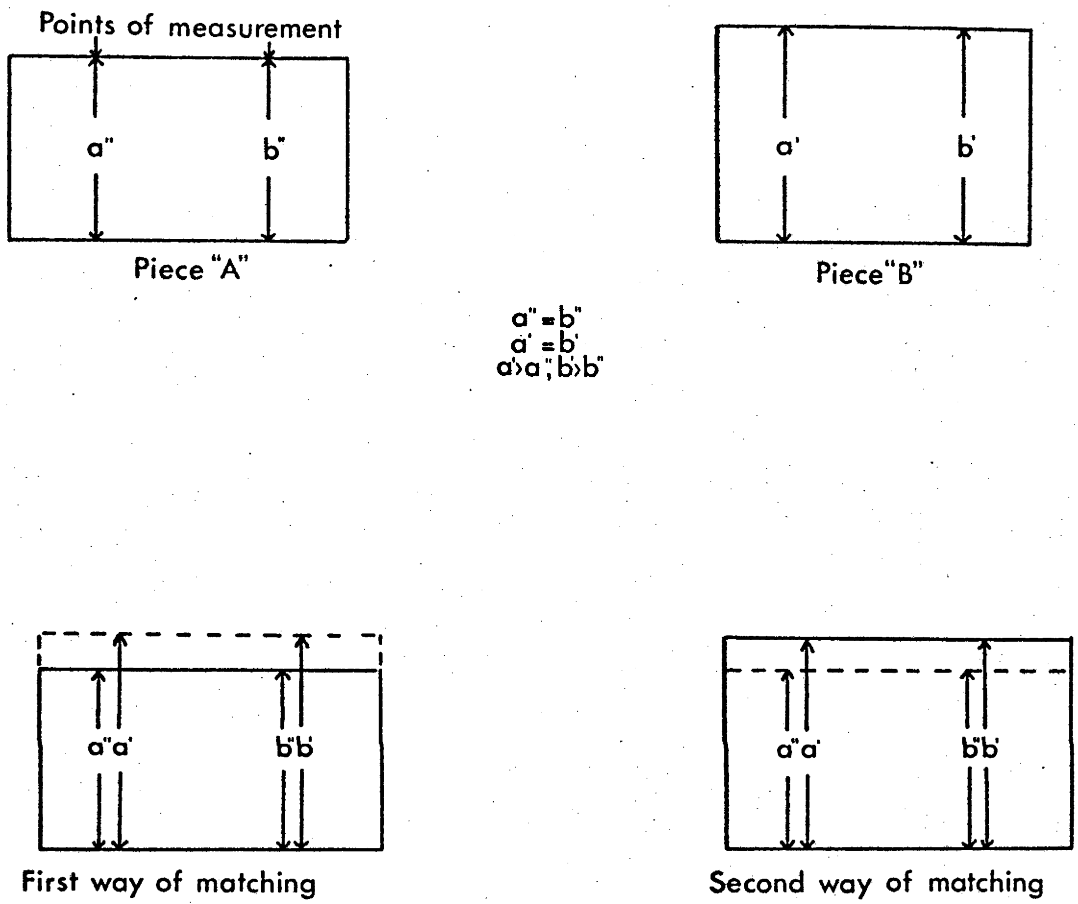
Two companies, Canberra Roof Trusses and Queanbeyan Roof Trusses, agreed to allow measurements to be taken at the joints of trusses fabricated at their plants to determine the actual thickness of timber used.

Readings were taken with a micrometer graduated to one thousandth of an inch. Three readings were taken across the width of each member of the joint. The readings were subsequently converted to metric units. Several visits were made to each plant over a period of about a year to obtain a good representation of the material used at each plant.

The timber species used in both truss plants was green Karri from Western Australia. The timber was dressed all round and the nominal thickness was 35 mm.

It was observed from the data collected that the thickness of some boards varied across the board. The difference in thickness at synthetic joints comprising two boards of uniform thickness is the difference between the readings for the thickness of the board. Figures 3.1 illustrate two ways of synthetically matching two boards, each of which varies in thickness, and the approximate average difference in thickness. In both cases the approximate difference in thickness equals the difference between the average thickness of the two boards and for both dressed and sawn timber the average thickness of the board has been adopted for the presentation and analysis of the results which involves synthesizing joints.

The number of readings obtained within various thickness classes are shown in Table 3.1.



$$\text{Average difference in thickness} = \frac{(a'-a'')+(b'-b'')}{2}$$

FIGURE 3.1.1

Average difference in thickness between two members of regular shape.

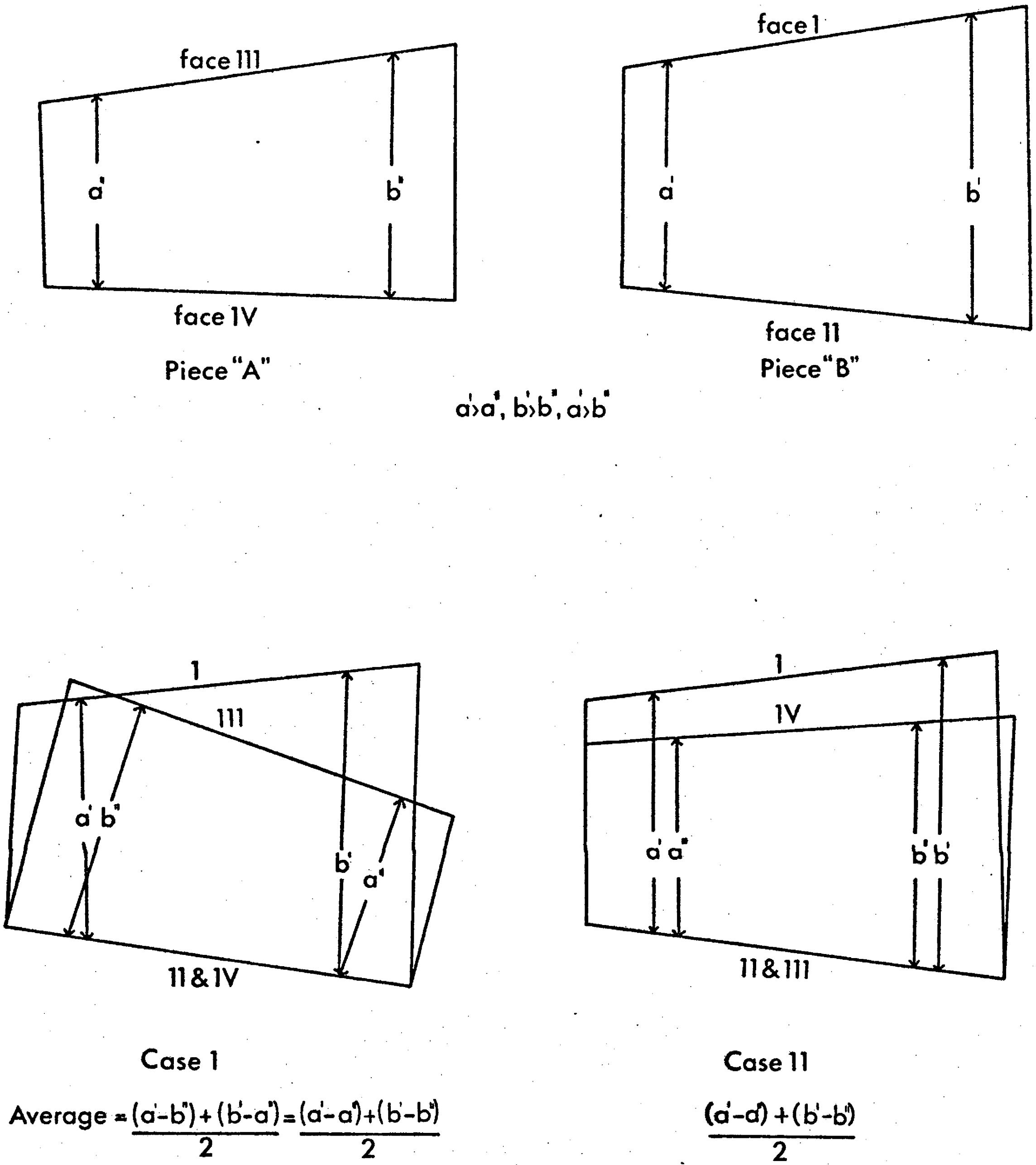


FIGURE 3.1.2

Average difference in thickness between two members of irregular thickness.

TABLE 3.1

Measured thicknesses of truss members at two truss fabrication plants.

THICKNESS mm	NUMBER OF OBSERVATIONS[1)] Queanbeyan Roof Trusses	Canberra Roof Trusses
33.14 - 33.26		2 (1)
33.27 - 33.39		3 (2)
33.40 - 33.52		4 (2)
33.53 - 33.65		4 (4)
33.66 - 33.78		5 (6)
33.79 - 33.91		7 (9)
33.92 - 33.04		8 (12)
34.05 - 34.17		6 (15)
34.18 - 34.30	10 (3)	13 (18)
34.31 - 34.43	21 (10)	20 (21)
34.44 - 34.56	34 (27)	25 (21)
34.57 - 34.69	68 (59)	19 (20)
34.70 - 34.82	106 (102)	19 (19)
34.83 - 34.95	192 (141)	16 (17)
34.96 - 35.08	166 (155)	19 (13)
35.09 - 35.21	103 (136)	18 (10)
35.22 - 35.34	59 (95)	16 (7)
35.35 - 35.47	34 (53)	5 (5)
35.48 - 35.60	13 (24)	
36.61 - 35.73	8 (8)	
35.74 - 35.86	3 (2)	
Total	817	209

1) Figures in brackets show expected number of observations for a normal distribution.

3.3 VARIABILITY OF THICKNESS OF SAWN TIMBER

The maximum tolerance in thickness for sawn hardwood is +4 mm in the Australian Timber Standards. The maximum difference in thickness of a timber joint fabricated with material meeting the Australian Standard should therefore be 4 mm. Although this should be a relatively rare occurrence the reduction in strength at this joint as reported in Chapter II would be unacceptably large but could be compensated by larger fasteners. The occurrence of such extreme differences in thickness could be avoided by specifying a maximum allowable difference in thickness of 2 mm but factory measurements, reported below, showed that differences in thickness greater than 2 mm would occur very frequently in practice.

Five sawmills were visited to obtain measurements of timber thickness.

No. 1 Circular saw breakdown and two-man bench resawing.
Species: Shining Gum
Location: Captain's Flat, New South Wales.

No. 2 Band saw breakdown and riderless carriage resawing.
Species: Alpine Ash
Location: Tumbarumba, New South Wales.

No. 3 Circular saw breakdown and riderless carriage resawing.
Species: Alpine Ash
Location: Esdaile, Victoria.

No. 4 Twin circular saw breakdown and two-man bench resawing.
Species: Alpine Ash
Location: Adaminaby, New South Wales.

No. 5 Circular saw breakdown and riderless carriage resawing.
Species: Alpine Ash
Location: Nimmitabel, New South Wales.

Thickness readings were taken along boards sawn from green timber as they came off the saw bench with a micrometer reading to a thousandth of an inch. The readings were taken at two points 15 mm away from each edge of the board at two or three sections along each board.

In the longer pieces the sections selected were about 50 cm away from the ends and at the mid section. In short pieces the sections selected were about 50 cm from each end of the board. In addition to determining variability in thickness the purpose of the measurements was to obtain thickness measurements which could be matched to form a synthetic joint and at which the difference in thickness could be calculated.

The nominal size of the timber measured was 4" × 2" (100 mm × 51 mm) and 4" × 1½" (100 mm × 38 mm) and the species Shining Gum (*Eucalyptus nitens*) and Alpine Ash (*Eucalyptus delegatensis)*. Several visits were made to Sawmill No. 1 as it was readily accessible but only one visit could be made to the other four mills as travelling time to each of these was at least one day. However in these four cases readings were taken over at least six hours of sawing. In the case of Sawmill No. 2 the saws were changed while the measurements were in progress and the measurements were classified into before-changing and after-changing saws.

The thickness readings at each of the five mills were grouped into size classes for both the nominal 2" (51 mm) and 1½" (38 mm). The number of readings in the size classes for the respective thicknesses are given in Tables 3.2 and 3.3.

3.4 ANALYSIS OF RESULTS

The analysis of results was undertaken at Ahlone Forest Station in Rangoon and all calculations done with a pocket calculator.

Tables 3.1, 3.2 and 3.3 include in brackets, after the number of measured observations the number of expected observations if the distribution of the measured observations had been normal. The histogram of the measured observations and the normal distribution curve for each mill are shown in Appendix 3.1.

The chi-squared test showed that in most cases the measured distributions were not significantly different from the expected frequencies of the normal distribution and it was therefore assumed that

TABLE 3.2

Measured thicknesses of sawn timber.
51 mm (2") nominal size

THICKNESS mm	NUMBER OF OBSERVATIONS[1)]					
	SAWMILL 1	SAWMILL 2 Before Sharpening	SAWMILL 2 After Sharpening	SAWMILL 3	SAWMILL 4	SAWMILL 5
46.3 - 46.7	1 (1)					2 (5)
46.8 - 47.2	3 (2)					6 (6)
47.3 - 47.7	7 (3)					9 (9)
47.8 - 48.2	6 (5)					15 (12)
48.3 - 48.7	8 (9)		- (1)			16 (14)
48.8 - 49.2	15 (12)	1	3 (2)	3 (1)		6 (13)
49.3 - 49.7	15 (17)	1 (1)	1 (4)	10 (4)		11 (11)
49.8 - 50.2	31 (19)	6 (2)	3 (7)	11 (7)		6 (8)
50.3 - 50.7	18 (22)	3 (4)	3 (10)	11 (17)	3 (-)	8 (5)
50.8 - 51.2	20 (24)	7 (7)	4 (12)	13 (22)	2 (1)	9 (3)
51.3 - 51.7	26 (22)	11 (10)	15 (12)	8 (25)	6 (3)	- (1)
51.8 - 52.2	16 (20)	11 (12)	9 (12)	21 (25)	9 (7)	1 (-)
52.3 - 52.7	9 (16)	12 (11)	7 (10)	35 (23)	11 (13)	
52.8 - 53.2	12 (12)	13 (10)	22 (7)	30 (18)	22 (20)	
53.3 - 53.7	6 (8)	2 (7)	12 (4)	29 (12)	20 (25)	
53.8 - 54.2	7 (5)	1 (4)	2 (2)	6 (8)	36 (26)	
54.3 - 54.7	3 (3)	4 (2)	2 (1)	1 (4)	22 (25)	
54.8 - 55.2	- (2)		2 (-)	1 (2)	19 (19)	
55.3 - 55.7	1 (1)				8 (12)	
55.8 - 56.2					4 (6)	
56.3 - 56.7					1 (3)	
Total	204	72	85	179	163	89

1) Figures in brackets show expected number of observations for a normal distribution.

TABLE 3.3

Measured thicknesses of sawn timber.
38 mm (1½") nominal size

THICKNESS mm	NUMBER OF OBSERVATIONS[1)] SAWMILL 1	SAWMILL 2 Before Sharpening	SAWMILL 2 After Sharpening	SAWMILL 3	SAWMILL 4	SAWMILL 5
33.1 - 33.5						1 (1)
33.6 - 34.0						3 (1)
34.1 - 34.5	6 (4)					2 (4)
34.6 - 35.0	19 (10)					9 (8)
35.1 - 35.5	27 (21)					26 (16)
35.6 - 36.0	43 (35)					33 (27)
36.1 - 36.5	64 (51)				1 (1)	41 (37)
36.6 - 37.0	78 (66)				2 (1)	57 (46)
37.1 - 37.5	67 (68)				2 (2)	53 (49)
37.6 - 38.0	40 (62)	2 (1)		2 (1)	4 (5)	34 (45)
38.1 - 38.5	38 (49)	2 (3)	2 (1)	3 (2)	4 (9)	22 (34)
38.6 - 39.0	25 (31)	7 (4)	4 (2)	3 (7)	11 (16)	17 (24)
39.1 - 39.5	15 (18)	6 (6)	3 (3)	4 (16)	19 (24)	10 (14)
39.6 - 40.0	5 (8)	4 (9)	5 (4)	19 (27)	19 (30)	1 (7)
40.1 - 40.5	4 (3)	13 (10)	3 (4)	27 (34)	30 (32)	5 (3)
40.6 - 41.0	1 (1)	15 (10)	2 (4)	37 (35)	33 (30)	3 (1)
41.1 - 41.5		5 (8)	2 (2)	45 (26)	37 (24)	
41.6 - 42.0		4 (6)	1 (1)	23 (15)	24 (16)	
42.1 - 42.5		2 (3)	1 (1)	7 (6)	14 (9)	
42.6 - 43.0		1 (2)		1 (2)	6 (5)	
Total	432	61	23	171	206	317

1) Figures in brackets show expected number of observations for a normal distribution.

a normal distribution would apply in the very large sample that could be obtained from a mill that is operated for a long period.

On the basis that the actual thicknesses of both sawn and dressed timber follow a normal distribution about the median thickness, as distinct from the nominal, estimates of the probability of occurrence of differences in thickness, when lengths of timber are randomly matched, were computed for each sawmill visited and the truss-making plants.

The method adopted was to prepare a matrix of thicknesses at the middle of the class intervals shown in Tables 3.1, 3.2 and 3.3 and assume that the expected observations shown in the tables actually occurred. The probabilities of the occurrence of various differences in thickness were then determined by calculating the probability associated with matching boards that would give each particular difference in thickness. The method assumes an infinitely large sample and this would be approximated with long term operation of the mills. An example of the matrix and the calculations is given in Appendix 3.2.

The calculated probabilities of occurrence of various differences in thickness using dressed timber from the two truss fabrication plants and sawn timber from each of the sawmills are given in Tables 3.4 and 3.5 respectively.

3.5 DISCUSSION OF RESULTS

Dressed Timber

Queanbeyan and Canberra Roof Trusses receive their timber supplies from different mills and while the median values of the timber thickness are only marginally different there is a bigger range of thickness in the material used by Canberra Roof Trusses.

Even with the material used by Canberra Roof Trusses it is highly probable, 999 chances in 1000, that the difference in thickness at the joints would be less than 2.0 mm, the maximum difference allowed in AS 1649-1974 "Determination of Basic Working Loads for Metal Fasteners".

TABLE 3.4

Probability of occurrence of difference in thickness.
Calculated values for dressed timber.[1)]

DIFFERENCE IN THICKNESS mm	CALCULATED PROBABILITY (1 in stated number)	
	Queanbeyan Roof Trusses	Canberra Roof Trusses
2.20		4080
2.07		930
1.94		360
1.81		170
1.68		80
1.55		
1.50	55000	
1.37	6400	
1.25	1300	
1.13	340	
1.00	106	

1) Based on the range of measurements shown in Table 3.1.

TABLE 3.5

Probability of occurrence of difference in thickness.
Calculated values for sawn timber.[1)]

DIFFERENCE IN THICKNESS mm	CALCULATED PROBABILITY (1 in stated number)									
	SAWMILL 1		SAWMILL 2		SAWMILL 3		SAWMILL 4		SAWMILL 5	
	51[2)]	35[2)]	51	35	51	35	51	35	51	35
9.0	20600									
8.5	4120									
8.0	1370									
7.5	560									50000
7.0	250									10000
6.5	120	22600						4160		2600
6.0	60	3000	3950		7000			1100		840
5.5		810	790		1000		4300	390		300
5.0		260	220	1730	270	7300	710	150	760	120
4.5		100	80	290	90	1220	185	70	150	50
4.0				80		280	60		50	
3.5						80				

1) Based on the range of measurements shown in Tables 3.2 and 3.3.
2) Nominal thickness mm (Table 3.2).
3) Nominal thickness mm (Table 3.3).

The performance of joints fabricated at the Queanbeyan plant could be marginally improved over those at Canberra Roof Trusses because of the smaller differences in thickness. For example there is a 1 in 1000 chance that the difference in thickness would exceed 2.0 mm at Canberra Roof Trusses whereas at Queanbeyan there is a 1 in 1000 chance that the difference would exceed about 1.3 mm. At this level of probability the reduction in difference in thickness of 0.7 mm would give a few per cent increase in strength. The actual values of the per cent increase in strength could be determined for specific species and fasteners from Table 2.13.

Sawn Timber

Inspection of Tables 3.2 and 3.3 shows that there are wide differences in the performance of the mills sampled relative to the nominal thickness and if all the data taken at the five sawmills were pooled there would be considerably higher probabilities of the occurrence of specified differences in thickness. Therefore if sawn timber is adopted for the fabrication of roof trusses then it would be more efficient to use material from one mill as this would reduce the number of joints at which the difference in thickness would exceed a specified tolerance and at which one member would have to be replaced. There seems no practical disadvantage in this, it simply entails that material from one mill would be batched through the truss plant, and it is concluded that sawn timber for each truss should in general be drawn from the same sawmill.

There are relatively high probabilities of large differences in thickness occurring at joints fabricated with 51 mm material from Sawmill No. 1 and 35 mm material from Sawmill No. 2. For example, there is about a 1 in 100 chance that with the 51 mm material from Sawmill No. 1 the difference in thickness at a joint would exceed 6.5 mm and that with 35 mm material from Sawmill No. 5 the difference would exceed 5.0 mm.

While such differences in thickness could be compensated in terms of load-carrying capacity by increasing plate size it is reasonable to assume, in view of the specialized nature of the timber requirements for roof truss manufacture, that timber should be obtained from mills with good tolerances rather than compensate for the larger differences in thickness from other mills.

In the case of the five sawmills studied the variability of the thickness of the 51 mm material from Sawmill No. 1 and the 35 mm material from Sawmill No. 5 is considerably greater than the remaining products and for the purposes of further analysis it is assumed that these two products would be unsuitable for roof truss production. That is the possibility of using sawn timber in roof truss fabrication is examined in relation to the variability of Sawmill No. 1 producing 35 mm boards, Sawmills 2, 3, and 4 producing 51 mm and 35 mm boards and Sawmill No. 5 producing 51 mm boards.

The data in Table 3.5, in relation to that in Table 2.13 enables assessment of the practicalities and requirements of using sawn timber for roof truss fabrication. For example, if all differences in thickness up to 5.0 mm were compensated in terms of load-carrying capacity by always using larger plates relative to what is required by existing design procedures then only joints exceeding this difference in thickness would be rejected, that is one of the members would then have to be replaced with a member of a thickness that would meet the specification. The probabilities of the occurrence of a difference in thickness greater than 5.0 mm, rounded from Table 3.5, are given below

Sawmill No. 1:	35 mm boards, 1 in 260
Sawmill No. 2:	51 mm boards, 1 in 220
	35 mm boards, 1 in 1700
Sawmill No. 3:	51 mm boards, 1 in 270
	35 mm boards, 1 in 7300
Sawmill No. 4:	51 mm boards, 1 in 700
	35 mm boards, 1 in 400
Sawmill No. 5:	51 mm boards, 1 in 760.

The significance of the relation between the occurrence of different thickness at joints, as calculated by synthesizing joints, and the compensation of the reduction in strength by increasing plate sizes is discussed in Chapter V.

Summary of Findings

1. The use of dressed timber at the two truss fabrication plants sampled enables differences in thickness at joints to be kept below 2 mm.

2. If sawn timber from some of the sawmills sampled was used for roof truss fabrication then relatively large differences in thickness would occur and it is concluded that the use of sawn timber would be efficient only if timber supplies were drawn from a mill with good control of sawing.

3. None of the mills studied operated with sawing tolerances that would enable differences in thickness at joints to be kept below 2 mm.

CHAPTER IV

THE SIGNIFICANCE OF TIMBER SHRINKAGE IN DETERMINING THE STRENGTH OF DRY TIMBER JOINTS

4.1 INTRODUCTION

Observations of the joints fabricated with green timber and allowed to dry before testing indicated that for all types of fasteners in both Karri and Ash the wood shrank away from the surface of the fastener and that there was loss of nail penetration as the timber dried out. Splitting of the timber along the grain was also apparent.

The significance of shrinkage of timber as a factor determining the strength of dry as compared to green timber joints when the fabrication is in green timber does not seem to be assessed in the literature. Measurements were therefore taken to determine the plate clearances from the wood as a result of shrinkage of the wood to enable both assessment of the significance of the shrinkage properties in relation to joint behaviour and conclusions to be drawn regarding the necessity of incorporating shrinkage into the classification of timber for the purpose of the engineering design of joints.

The possible significance of shrinkage was not appreciated until observations were made on dried joints and the magnitude of the reduction of strength as a result of loss of nail penetration had been determined as in Chapter II. The opportunity to readily measure plate clearances as a result of shrinkage in some of the joints tested, and discussed in Chapter II, was consequently missed and alternative procedures were therefore necessary.

The theoretical approach adopted was to assess the significance of the loss of penetration of nails as a result of shrinkage, compare this loss with other factors affecting the strength of dry as compared to green joints and check the estimated loss of penetration of the nails by actual measurement on a number of joints.

4.2 ESTIMATES OF LOSS OF NAIL PENETRATION AND STRENGTH DUE TO SHRINKAGE

The shrinkage values for both Karri and Ash are set out in Table 4.1.

TABLE 4.1

Shrinkage properties Karri and Alpine Ash.

SPECIES	SHRINKAGE % (Green to 12% Moisture Content)			
	Tangential		Radial	
	Mean	95% Probability Range	Mean	95% Probability Range
Alpine Ash	8.5	4.1 - 12.2	5.2	1.1 - 7.7
Karri	9.9	6.2 - 13.9	4.3	2.0 - 6.8

Source: Shrinkage and Density of Australian and Other Woods. Division of Forest Products Technological Paper No. 13. Commonwealth Scientific and Industrial Research Organization, Australia. 1961.

If it is assumed that the mean shrinkage shown in Table 4.1 occurs over the full depth of the teeth and is towards the tip of the tooth then the gross loss of tooth penetration can be calculated. The calculated values are shown in Table 4.2. The values shown are, on the basis of the assumptions, the maximum "average" value of the loss of penetration that could occur. Frictional forces between the nail and the wood would act to restrain the wood as it tended to shrink away from the plates and thus tend to reduce the loss of penetration. There would then be internal tension stresses developed in the wood in a direction perpendicular to the grain across the thickness of the board.

TABLE 4.2

Calculated gross loss of tooth penetration with shrinkage of timber thickness at joints.

TYPE OF FASTENER	LENGTH OF TOOTH mm	GROSS LOSS OF PENETRATION (mm) KARRI Tangential[1]	Radial[1]	ALPINE ASH Tangential	Radial
Gangnail I	11	2.2	0.9	1.9	1.1
"	14	2.8	1.2	2.4	1.5
Gangnail II	15	3.0	1.3	2.6	1.6
Steelfast I	17	3.4	1.5	2.9	1.8
Steelfast II	17	3.4	1.5	2.9	1.8
Sanford I	10	2.0	0.9	1.7	1.0
Sanford II	10	2.0	0.9	1.7	1.0

1) Tangential or Radial shrinkage along the tooth.

The investigations reported in Chapter II enable prediction of the loss of strength of joints as a result of loss of penetration of the teeth. On the basis that the loss of strength would be as shown in Table 2.13 and the loss of penetration as in Table 4.2 the percentage reduction in strength as a result of shrinkage can be calculated and is shown in Table 4.3.

TABLE 4.3

Calculated percentage reduction in strength as a consequence of timber shrinkage.[1]

TYPE OF PLATE	KARRI Tangential	Radial	ALPINE ASH Tangential	Radial
Gangnail II	16	7	13	8
Steelfast I	15	6	16	10
Steelfast II	23	10	15	10
Sanford I	13	6	14	8

1) Based on green values in Table 2.13.

However shrinkage of the timber thickness is not the only factor involved in estimating the strength in the dry condition of timber joints prepared in the green condition. The strength properties of timber change and in particular there is an increase in compressive strength in a direction parallel to the grain. It is in this direction that in tension tests the load is transferred to the timber by the nail and on this basis an increase in strength of the timber joints in the dry relative to the green condition would be expected.

The increase in strength in a direction parallel to the grain of Karri and Alpine Ash due to drying are shown in Table 4.4. Even allowing for the reduced area of wood after shrinkage the increases would be greater than the calculated reduction due to loss of penetration as a consequence of shrinkage as given in Table 4.3. It is usual in practice to allow a 25% increase for dry strengths to green when using the nominal size in green timber.

TABLE 4.4

Compressive strength of Karri and Alpine Ash parallel to grain.[1)]
(Megapascals)

SPECIES	STRESS AT LIMIT OF PROPORTIONALITY			MAXIMUM CRUSHING STRENGTH		
	Green	Dry	Increase[2)]	Green	Dry	Increase[2)]
Karri	28.8	50.0	74%	36.2	71.7	98%
Alpine Ash	28.4	41.9	47%	33.5	59.9	79%

1) Source: Division of Forest Products Technological Paper No. 25X *op. cit.* Table 4.1.

2) Green to dry condition.

It is clear from Tables 4.3 and 4.4 that the change in strength as joints fabricated in the green condition dry out cannot be explained in terms of loss of nail penetration due to shrinkage and an increase in the strength of timber parallel to the grain.

As mentioned previously splitting of timber along the grain was observed as a result of shrinkage across the width of the timber members of a joint. It seems that this splitting may occur at the side of the nails of the fasteners although this could not be observed as the splitting was below the plate and not therefore visible. If such splitting did occur then whereas in the green condition failure of the timber behind the teeth as the load is applied in a tension test would require a shear failure along the sides of the teeth this would not be required in the dry condition. That is the full resistance would be provided in compression parallel to the grain in the dry condition.

The shear strengths of Karri and Alpine Ash in the green condition are shown in Table 4.5. It can be deduced from these values that the shear resistance of the wood could make a significant contribution to the load-carrying capacity of green timber joints.

TABLE 4.5

Shear strength of Karri and Alpine Ash.[1]
(Megapascals)

SPECIES	MAXIMUM SHEAR STRENGTH	
	Radial	Tangential
Karri	8.3	10.0
Alpine Ash	7.7	8.5

1) Source: Division of Forest Products Technological Paper No. 25X *op. cit.* Table 4.1

Take for example a tooth of average width 3 mm and 15 mm depth. The area bearing on the wood is 45 sq. mm. If the tooth moves an average of 0.5 mm in the direction of the load then shear forces would be developed over an area 7.5 sq. mm on each side of the tooth, that is a total area of 15 sq. mm. While the shear strengths shown in Table 4.5 are only about one quarter to one third of the values shown in Table 4.4 for compression parallel to the grain it seems that the shear resistance at the sides of the teeth in green joints could make a significant contribution to the strength of the green joints. The measurements necessary to determine the significance of the shear strengths was beyond the scope of this study but it is suggested that an experimental or theoretical analysis would assist in describing the fundamental mechanics of the behaviour of green and dry joints.

4.3 MEASUREMENTS OF PLATE CLEARANCE DUE TO SHRINKAGE

It was not intended to measure the plate clearances when the joints were prepared with green timber for the main study of the effects on strength of differences in thickness and datums were not established to enable direct measurement of plate clearances on most of the specimens. Two approaches were adopted to obtain information readily available as it was not feasible to prepare joints specifically for the measurement of plate clearances due to shrinkage.

4.3.1 Measurements on Joints Prepared for Strength Tests

The joints prepared for strength testing were pressed in such a way, as described in Chapter II, as to ensure full penetration of the teeth. Assuming therefore that there was zero plate clearance when the joints were pressed green then measurement of the plate clearance in the dried condition would provide a measure of the plate clearance due to shrinkage.

Measurements of the plate clearance in the dried joints was made for all available joints by using a depth micrometer to measure the depth from the top of the plate to the wood, under selected openings in the plates and subtracting the thickness of the plate to determine the clearance. The openings were those formed in the manufacture of the plate by punching the teeth. The method assumes that there was zero plate clearance at the time the joints were pressed and that there was no crushing of the wood in the pressing process. The reliability of the measurements would have been enhanced if actual measurement of the plate to wood clearance at the selected points could have been made but no practical method could be developed.

The measurements are summarized in Table 4.6.1.

TABLE 4.6.1

Plate clearances due to shrinkage.
(Based on measurements on dried joints)

PLATE	SPECIES	TEST SERIES	No. READINGS	PLATE CLEARANCE Mean mm	Standard Deviation	Standard Error
Steelfast	Alpine Ash	1	100	1.67	0.60	0.060
		2	156	1.50	0.45	0.036
		3	100	1.50	0.32	0.032
		4	64	1.57	0.25	0.031
Sanford	Alpine Ash	1	48	0.75	0.20	0.028
		2	107	0.76	0.20	0.019
		3	152	0.77	0.28	0.022
	Karri	1	90	0.57	0.22	0.024
		2	135	0.75	0.32	0.028

4.3.2 Measurements of Joints Prepared for Basic Testing of Sanford Fasteners

The opportunity was taken to obtain measurements of the depth to the wood below the surface of the plate,in both the green and dry condition at the same point, of joints prepared to determine the basic working loads of Sanford metal fasteners. The depth to the wood was measured with a depth micrometer and the difference between the depths in the green and dry condition taken as the plate clearance. The time between the two readings was about five months, the period required for the joints to dry. There was no certainty that the second measurement was taken at exactly the same point as the first.

The measurements are summarized in Table 4.6.2.

TABLE 4.6.2

Plate clearances due to shrinkage.
(Based on measurements on joints with Sanford plates)

PLATE	SPECIES	No. READINGS	PLATE CLEARANCE Mean mm	Standard Deviation	Standard Error
Sanford	Alpine Ash	91	0.60	0.27	0.028
	Karri	274	0.27	0.19	0.011
	Messmate	79	0.41	0.17	0.019

4.3.3 Discussion of Results

The rather crude methods for measuring the plate clearance and the lack of a method to measure the clearance under the plate rather than at the openings in the plates cast some doubts on the accuracy and reliability of the measurements for the calculation of plate clearances and a statistical analysis has not been attempted.

Nevertheless the results provide some evidence of the actual magnitude of the plate clearances and when compared with the calculated values of the gross loss of tooth penetration with shrinkage of timber thickness at joints shown in Table 4.2 confirm the theoretical analysis presented in Section 4.2.

The values shown in Table 4.2 represent the loss of penetration at a joint and half of these values would occur each side of the joint, that is at one tooth. The calculated values per tooth, based on Table 4.2 and the measured values are shown in Table 4.7.

The data in Table 4.7 suggests that the actual increase in plate clearance due to shrinkage would not exceed the calculated values allowing tangential shrinkage. It supports the basis of the contention in Section 4.2 that "the change in strength as joints fabricated in the green condition dry out cannot be explained in terms of loss of nail penetration due to shrinkage and an increase in the strength of timber parallel to the grain."

TABLE 4.7

Calculated and measured values of plate clearance.

PLATE	SPECIES	CALCULATED CLEARANCE[1)] Tangential Shrinkage	Radial Shrinkage	MEASURED CLEARANCE Dry Joints[2)]	Green and Dry Joints[3)]
Steelfast	Alpine Ash	1.5	0.90	1.7 (1)	
				1.5 (2)	
				1.5 (3)	
				1.6 (4)	
Sanford	Alpine Ash	0.85	0.50	0.8 (1)	0.6
				0.8 (2)	
				0.8 (3)	
	Karri	1.0	0.45	0.6 (1)	0.3
				0.8 (2)	

1) Based on Table 4.2.
2) See Table 4.6.1.
3) See Table 4.6.2.

It is accepted therefore that the information provided by the results of this study on the loss of strength as a result of a reduction in the penetration of the nails of metal fasteners into wood does not provide sufficient evidence for the incorporation of shrinkage into the design procedures for timber joints.

CHAPTER V

THE SELECTION AND SPECIFICATION OF SAWN TIMBER FOR ROOF TRUSS FABRICATION

5.1 INTRODUCTION

The investigations undertaken to investigate the effect of difference in thickness between the members of timber joints fabricated with metal fasteners has shown that if the difference in thickness results in a loss of penetration of the nails then there is a reduction in strength of the joint which is directly proportional to the difference in thickness.

The actual differences for each 2 mm of difference in thickness is summarized in Table 2.13 for the species and plates examined.

It would be feasible to compensate for the reduction in strength of joints as a consequence of a difference in thickness by increasing the size of the plates at the joint. If the additional cost of the plates to compensate for the larger differences in thickness that would occur if sawn timber was used instead of dressed timber is less than the cost of dressing the timber then, in respect of the strength of the joint, it would be economic to use sawn timber.

Other factors would also influence the choice of sawn material. For example there would be some increase in strength of the members acting as beams or columns because of the larger size of the members as compared to dressed material of reduced section. There would also be increased difficulty in accurately setting the jigs to hold the truss members in place while the joints are pressed. These other factors are outside the scope of this study and assessment of their significance would require the experience and technical knowledge of timber truss fabricators.

A study of the relative costs of dressing timber and the additional costs of plates to compensate for the differences in thickness that would occur if sawn timber was used to fabricate trusses would require commercial information from the timber industry and timber truss fabricators. This data was not available and the commercial significance of the results of this study can therefore only be examined in an overall way. In practice it would be necessary for each truss fabricator to make an independent assessment taking into account the particular factors relevant to each plant.

5.2 FEASIBILITY OF USING SAWN TIMBER FOR TIMBER ROOF TRUSSES

AS 1649-1974 (*op. cit.* p.5) allows a 2 mm difference in thickness in testing joints and AS 1720-1975, the Timber Engineering Code, requires that "at the time of fabrication, the maximum difference in thickness between any two of the several members at a joint shall not exceed 2 mm." Thus in practical terms it is the decrease in strength as a result of a difference in thickness greater than 2 mm that would need to be compensated by increased plate sizes if sawn timber were adopted, as the existing design tooth loads, based on a maximum difference of 2 mm, have in general been used for dressed timber.

While the study has established the decrease in strength for plates produced by three manufacturers and for three species classified into different joint groups in AS 1720-1975 the studies are not comprehensive and may require extension to other species. Therefore for the purposes of the following analysis a range of percentage reductions in strength per mm of difference in thickness are assumed rather than undertaking an analysis in terms of specific species and fasteners although this would be necessary for a practical feasibility analysis.

Table 5.1 summarizes the probabilities of the occurrence of differences in thickness at joints fabricated with the higher quality timber, in terms of sawing tolerances, from the sawmills sampled. The percentage decrease in strength that would occur with these differences for decreases in strength of 5%, 7% and 9% per mm difference in

TABLE 5.1

Probabilities of occurrence of differences in thickness at joints and corresponding reductions in strength.

DIFFERENCE IN THICKNESS	PROBABILITIES OF OCCURRENCE OF DIFFERENCE IN THICKNESS[1] (1 in Stated Number)								DECREASE IN STRENGTH[2,3] %		
	Mill No. 1	Mill No. 2		Mill No. 3		Mill No. 4		Mill No. 5	% Reduction/mm Difference in Thickness[4]		
mm	35	51	35	51	35	51	35	51	5	7	9
6.0	3000	4000		7000			4200		30 (20)	42 (28)	54 (36)
5.5	800	800		1000		4300	1100		28 (18)	38 (24)	48 (32)
5.0	260	220	1700	270	7300	700	400	760	25 (15)	35 (21)	45 (27)
4.5	100	80	300	90	1200	190	150	150	23 (13)	32 (18)	41 (23)
4.0			80		280	60	70	50	20 (10)	28 (14)	36 (18)
3.5									18 (8)	25 (11)	32 (14)

1) See Table 3.5.

2) Decrease in strength as a result of difference in thickness.

3) Figures in brackets represent reduction as a consequence of differences in thickness of greater than 2 mm.

4) Actual values can be obtained for specific species and fasteners from Table 2.13.

thickness are also shown. The decreases in strength for these percentages on the basis that the practical decrease in strength would be for differences in thickness over and above 2 mm are shown in brackets.

Table 5.1 enables assessment of the use of sawn timber for roof truss manufacture. For example if plate sizes were increased by say 25% by reducing the basic working loads per tooth by 20% then for a reduction of 7% per mm difference of thickness a difference in thickness of up to say 5.0 mm could be accepted without significantly changing the load that the joint could withstand. There would be 1 chance in 260 that this difference in thickness would be exceeded with 35 mm timber from Mill No. 1 and 1 chance in 7300 that it would be exceeded in the case of 35 mm timber from Mill No. 3.

The analysis presented in Table 2.14 showed that the type of plate is more critical than species in determining the reduction in strength as a consequence of differences in thickness. This is also apparent from Table 2.13. The Steelfast fasteners show the smallest reduction in strength and the Sanford the largest. However the Sanford fasteners are in practice pressed through rollers in a wringer-like action and it is unlikely that the reduction in the penetration of the nails would be as great as the difference in thickness.

It is concluded that it would be feasible to use sawn timber for roof truss manufacture by careful selection of the sawmill from which timber supplies are drawn to reduce the probability of occurrence of relatively large thicknesses in timber. An increase in the size of plates relative to using dressed timber would be necessary. The "Basic Working Loads" of the toothed metal fasteners could be modified to ensure this and the loads could be specified in terms of the maximum difference in thickness that would be permitted at a joint. The maximum difference in thickness permitted should be specified in relation to the variability in thickness of the timber from the mill supplying timber and this should be determined by the truss fabricator.

5.3 ECONOMICS OF USING SAWN TIMBER

Apart from the technicalities associated with the engineering design of joints that may have relatively large differences in thickness it is desirable that the joints be optimal in terms of cost, that is the savings that would accrue by using sawn timber instead of dressed timber would offset the additional cost of the larger plates that would be required. The commercial information for this was not available.

While each truss fabricator should undertake an economic feasibility study before choosing sawn timber in preference to dressed material, the general information in Table 5.2 provides a guideline to the break-even point of using sawn and dressed timber. For example, if the cost of dressing timber is $2.00 per truss and it would be necessary to increase the cost of the plate by 25% to allow for the difference in thickness that would occur with sawn timber then it would be economic in terms of material costs to use rough sawn timber if the cost of metal fasteners using dressed timber is less than $8.00.

TABLE 5.2

Highest cost of metal fasteners providing savings in material costs if timber is not dressed.

COST OF DRESSING PER TRUSS $	COST OF METAL FASTENERS[1] (per Truss with Dressed Timber) $			
	10%	15%	20%	25%
	Percentage Increase in Cost of Metal Fasteners to Compensate for Sawn Timber[2]			
0.5	5.0	3.3	2.5	2.0
1.0	10.0	6.6	5.0	4.0
1.5	15.0	9.9	7.5	6.0
2.0	20.0	13.2	10.0	8.0
2.5	25.0	16.6	12.5	10.0

1) The actual cost of purchasing fasteners for trusses fabricated with dressed timber.

2) The percentages represent increased costs of purchasing fasteners if sawn timber is used instead of dressed timber.

REFERENCES

Australian Standards

AS1490-1973. Visually Stress Graded Radiata Pine for Structural Purposes.

AS1649-1974. Methods for the Determination of Basic Working Loads for Metal Fasteners for Timbers.

AS1720-1975. SAA Timber Engineering Code.

Published by The Standards Association of Australia, Standards House, North Sydney, Australia.

Titmus, L.F. 1972 Study of the Use of Structural Timber in the Australian Capital Territory. Honours Thesis. Department of Forestry. Australian National University, Canberra.

Stodart, D.M. 1972 Timber Roof Trusses in the Australian Capital Territory: An Appraisal of their Use and Performance. Proceedings 1972 Gangnail Seminar. Automated Building Components (Aust.) Pty. Ltd., Melbourne.

Wymond, A.P. 1975 Trends in the Market for Sawn Building Timber in Australia. Australian Forest Industries, Vol. 41, No. 4.

APPENDIX 2.1
Sheet 1

DEPARTMENT OF FORESTRY

AUSTRALIAN NATIONAL UNIVERSITY

JOINT TESTS FOR SANFORD TRUSS AUSTRALIA

SUMMARY OF RESULTS

PECIES	PLATE TYPE Joint type[2]		TOOTH LOADS NEWTONS/TOOTH[1]			
			Plate slots Parallel to grain[3]		Plate slots Perpendicular to grain[3]	
			Green[4]	Dry[4]	Green[4]	dry[4]
arri	Staggered slots					
	T.1.	a[5]		117[6]		84[6]
		b[7]		145	104[8]	76[8]
		c[9]	143			
		d[10]	145	116		
	T.2.		54[11]	54[11]	57[12]	87[12]
			75[8]	86[8]	74[7]	106[7]
	Parallel slots					
	T.1				139[8]	152[8]
		c[9]	152			
	T.2	a[5]			87[12]	79[12]
		d[10]	148[8] [14]	82[8]		
Radiata	Staggered slots					
	T.1	a[5]		111		62[6]
		b[7]		114		89[8]
	T.2	a[5]		36[11]		59
		b[7]		71[8]		78[8]
	Parallel slots					
	T.1	b[7]		126		
	T.2	a[5]				65[12]

APPENDIX 2.1
Sheet 2

PECIES	PLATE TYPE Joint type[2]		TOOTH LOADS NEWTONS/TOOTH[1] Plate slots Parallel to grain[3] Green[4]	Dry[4]	Plate slots Perpendicular to grain[3] Green[4]	dry[4]
lpine sh	Staggered slots					
	T.1	a[5]	122	138[13]		
		b[7]	142	114[13]	109[8]	128[8]
	T.2	a[5]			84	94[12]
		b[7]	99[8]	104[8]		
ess-ate	Staggered slots					
	T.1	a[5]				70[11]
		b		127[6][13]		72[8]
	T.2	a[5]		30[11]	70	59[12]
		b[7]		57[8]	110[12]	72[12]

) Calculated in accordance with AS 1649-1974 and in each case based on 1% probability limit of the maximum load

) AS 1649-1974, page 17

) The direction of the grain is for the horizontal member in Type 2 joints

) Moisture contents of tested joints. All hardwood joints fabricated green, radiata pine joints fabricated from dry wood

) End and edge teeth not removed to check edge effect

) Plate failure in green specimens

) End or edge teeth removed. See AS 1649-1974

) Specially fabricated plate to ensure tooth withdrawals

) End and side teeth removed

) Side teeth removed to ensure tooth withdrawal

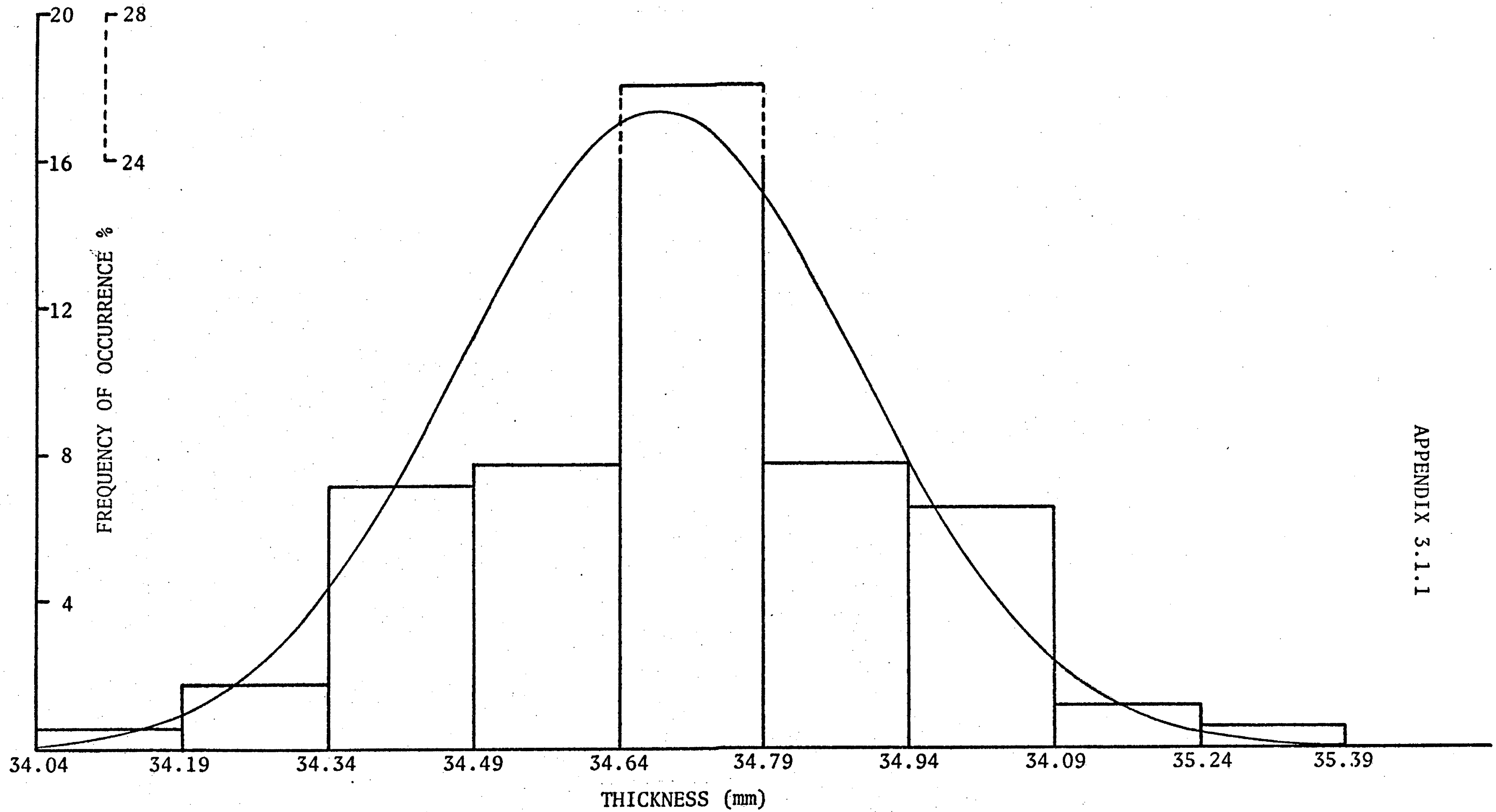
) Special test to check edge effect

) Tooth withdrawal associated with splitting due to tension perpendicular to grain

) Additional teeth cut from dry specimens to ensure tooth withdrawal

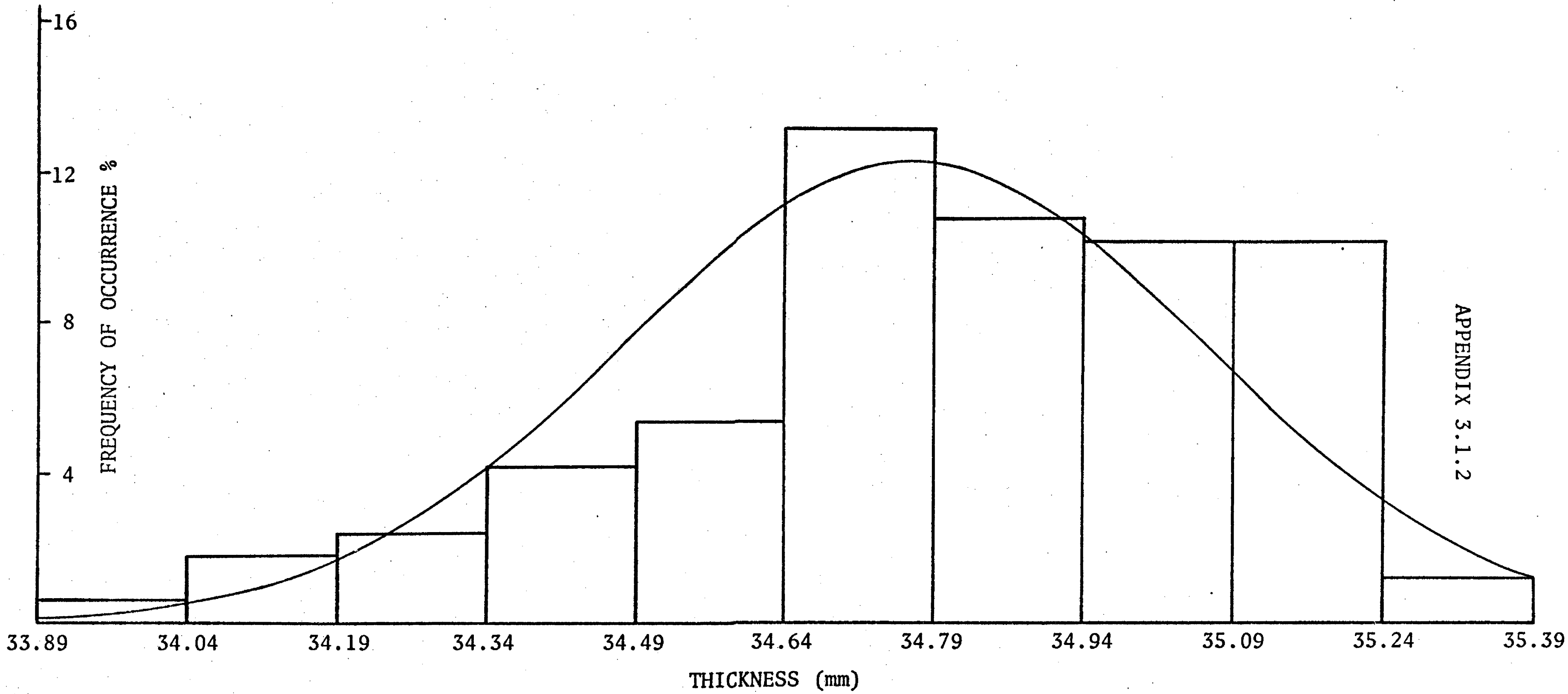
) One row teeth only

APPENDIX 3.1.1



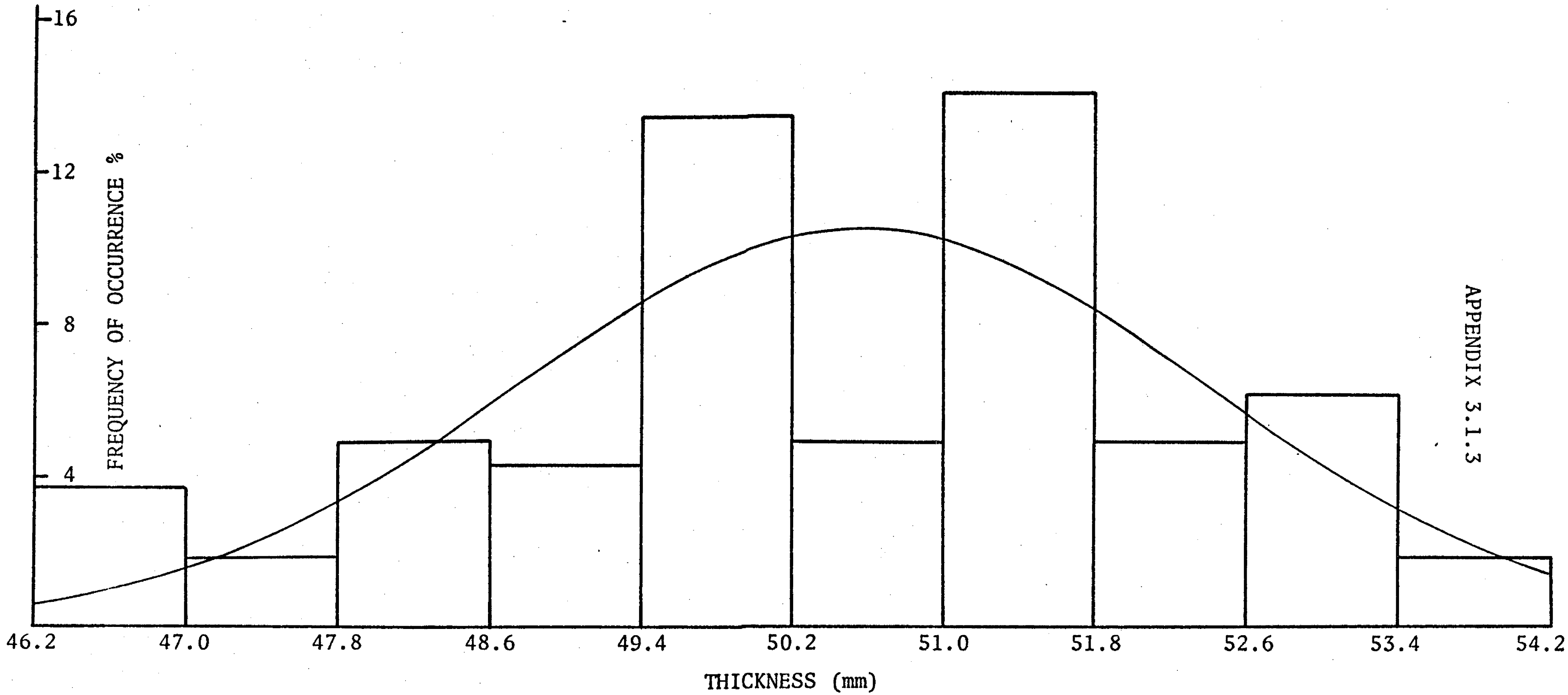
Histogram of measured thicknesses and normal distribution of timber thickness.
Queanbeyan Roof Trusses.

APPENDIX 3.1.2



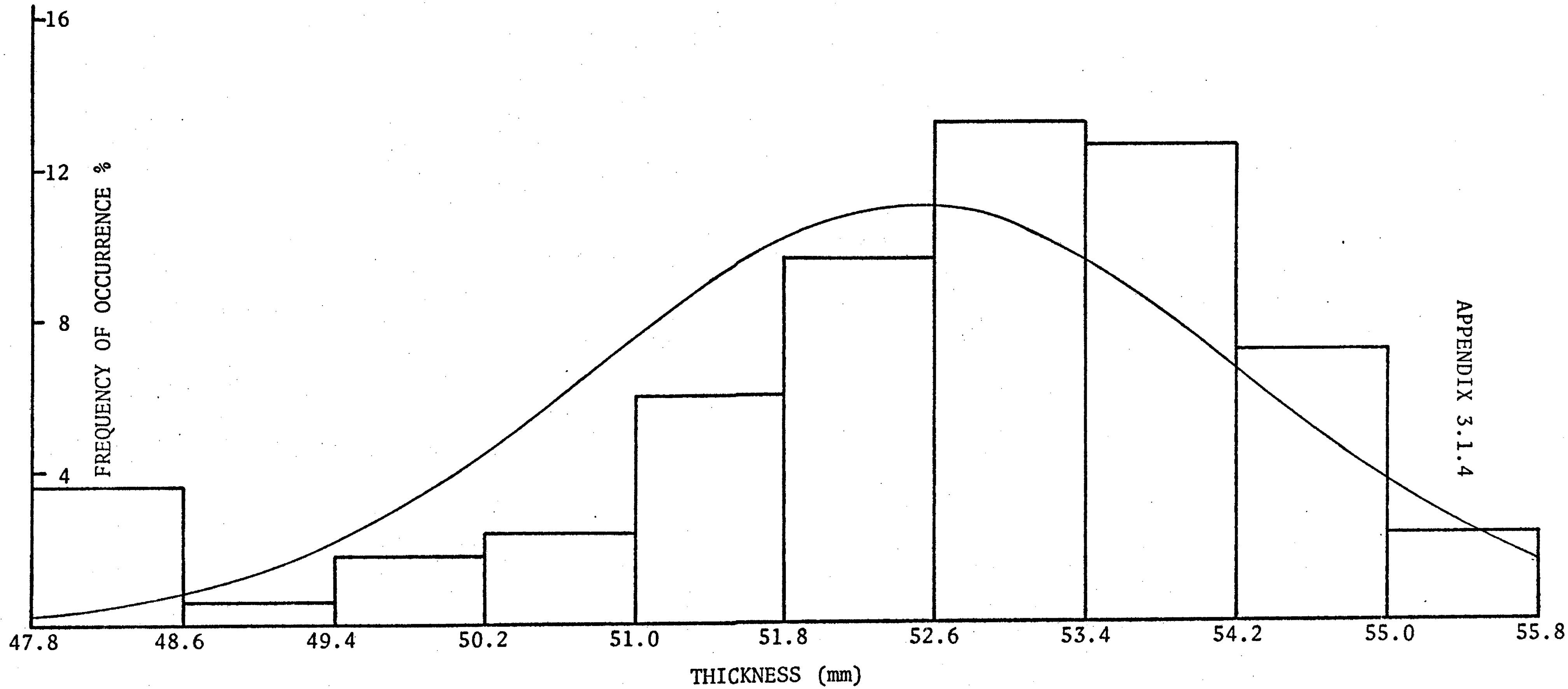
Histogram of measured thickness and normal distribution of timber thickness.
Canberra Roof Trusses.

APPENDIX 3.1.3



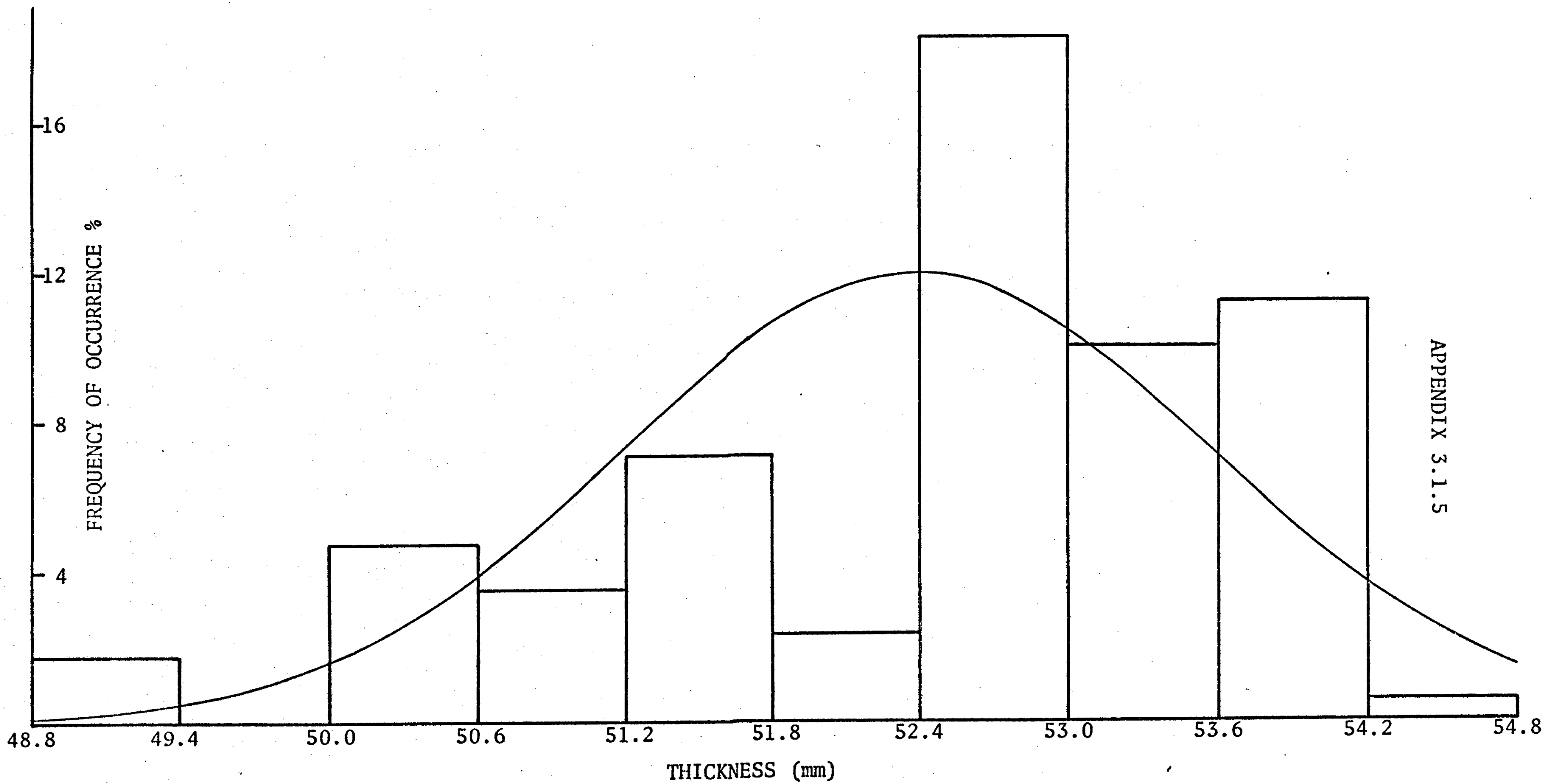
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 1. 51 mm nominal thickness.

APPENDIX 3.1.4



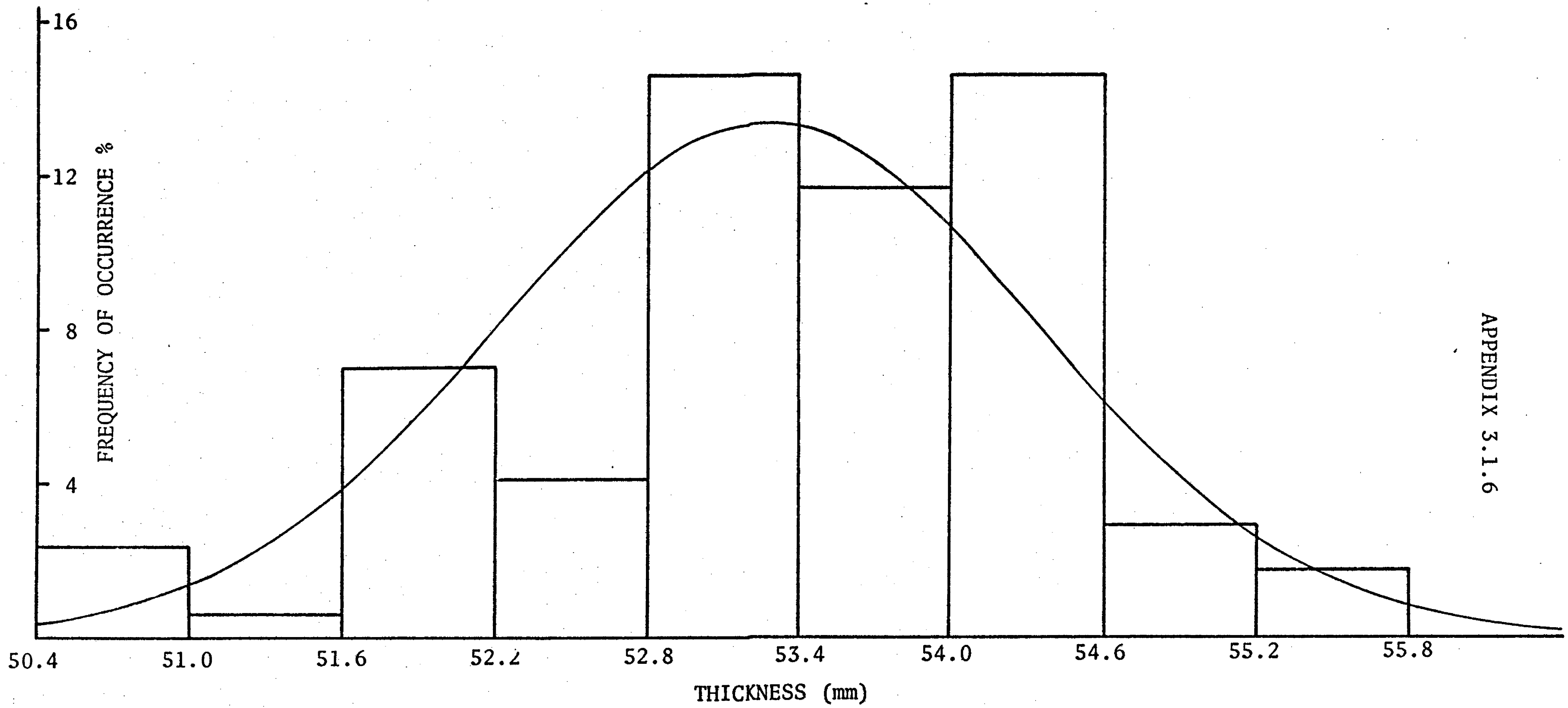
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 2. 51 mm nominal thickness.

APPENDIX 3.1.5



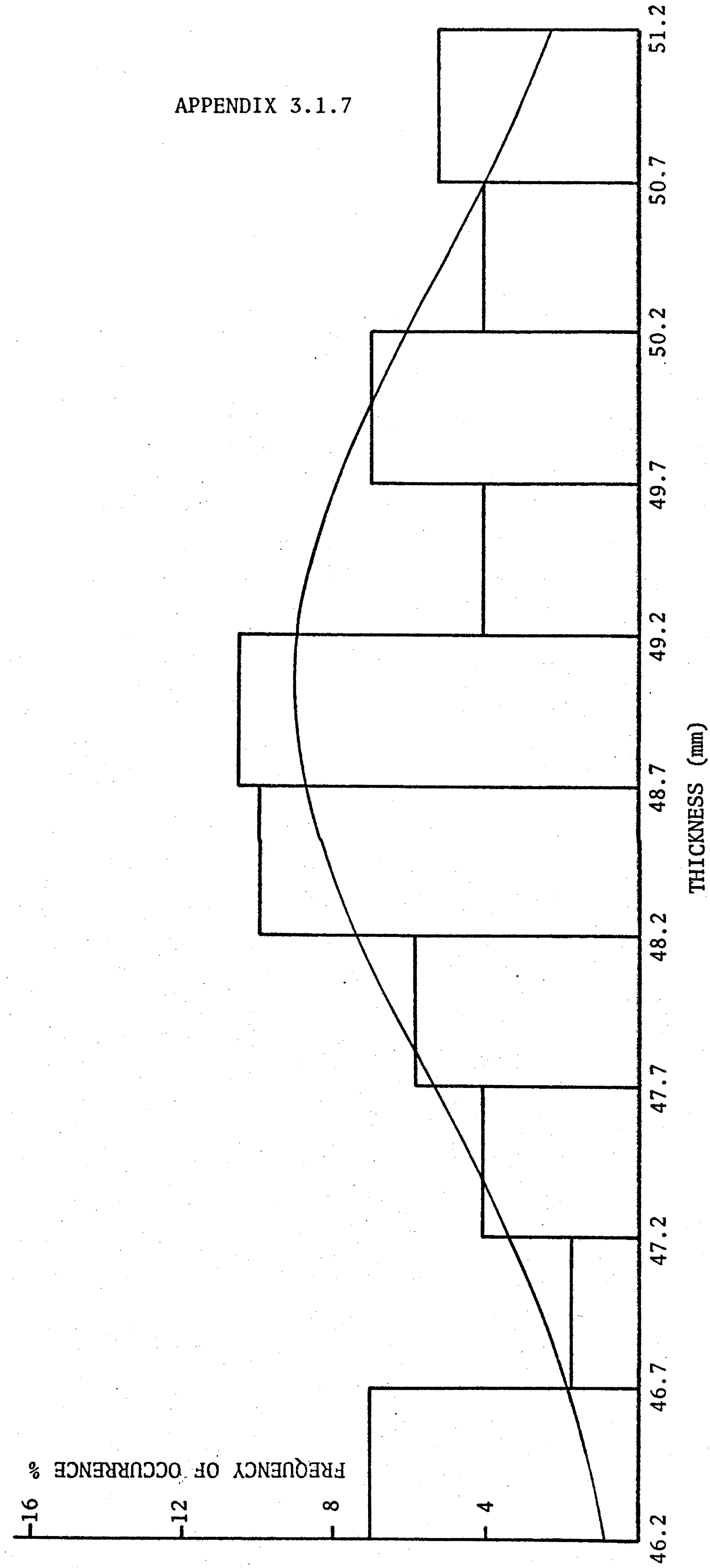
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 3. 51 mm nominal thickness.

APPENDIX 3.1.6



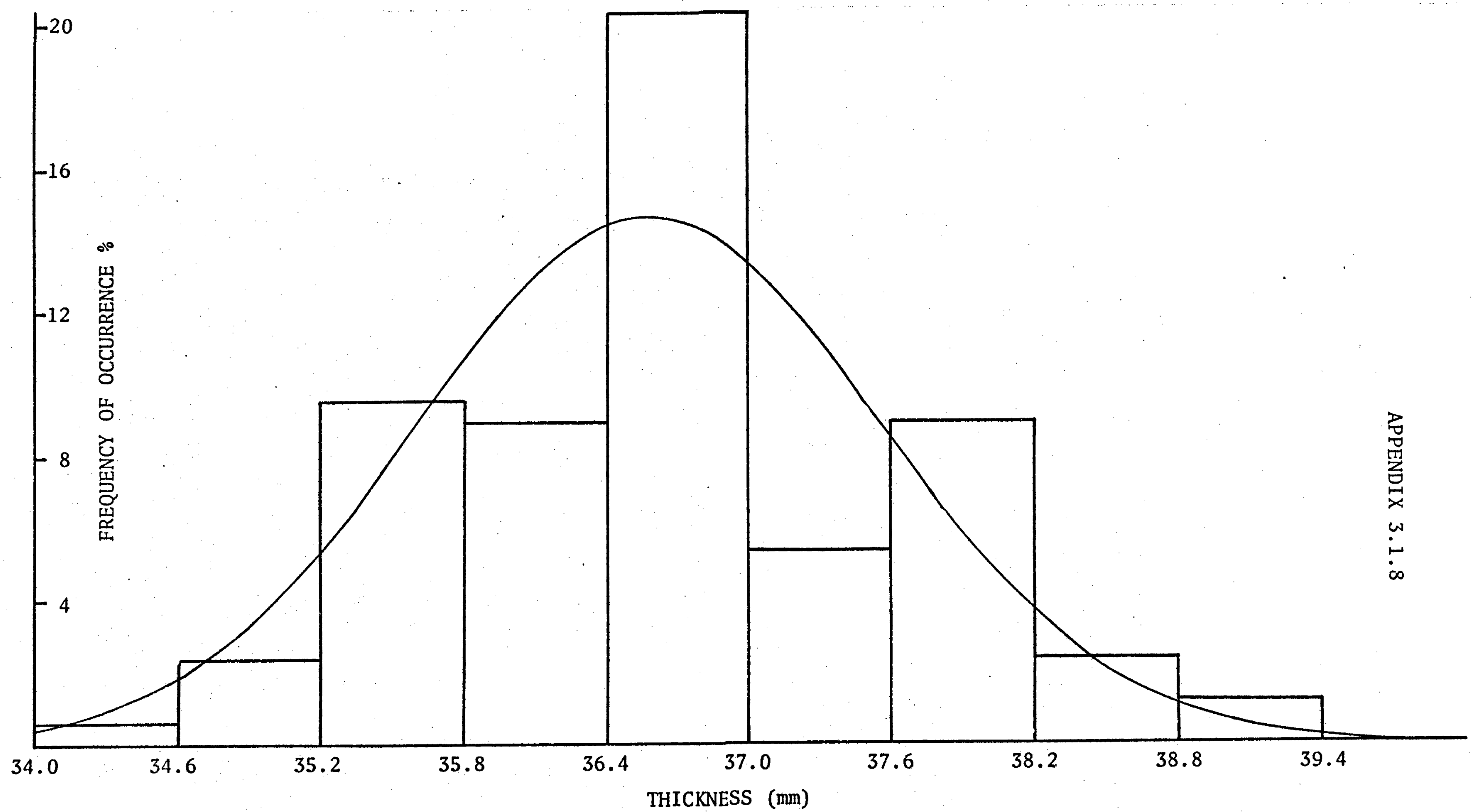
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 4. 51 mm nominal thickness.

APPENDIX 3.1.7



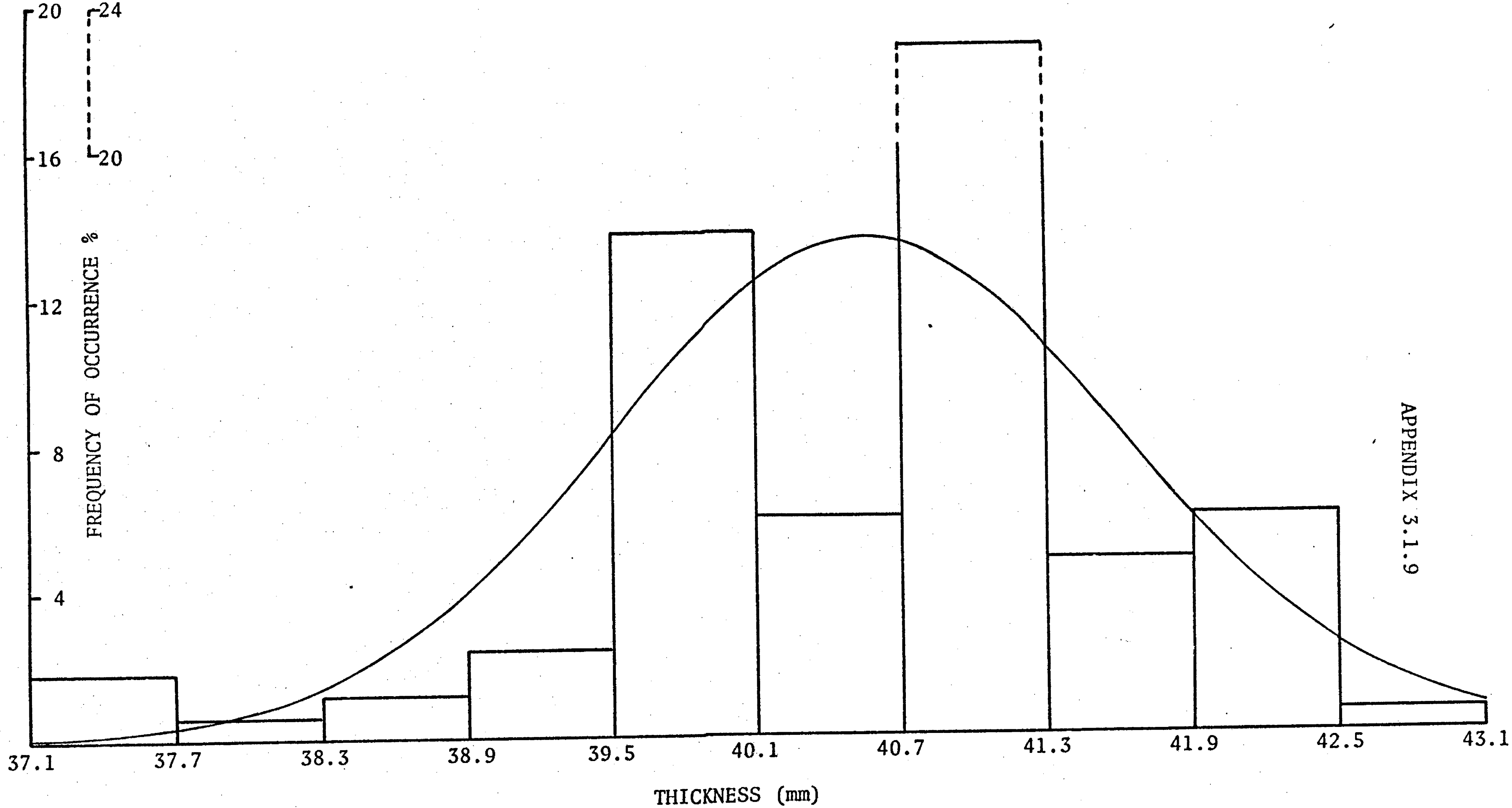
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 5. 51 mm nominal thickness.

APPENDIX 3.1.8



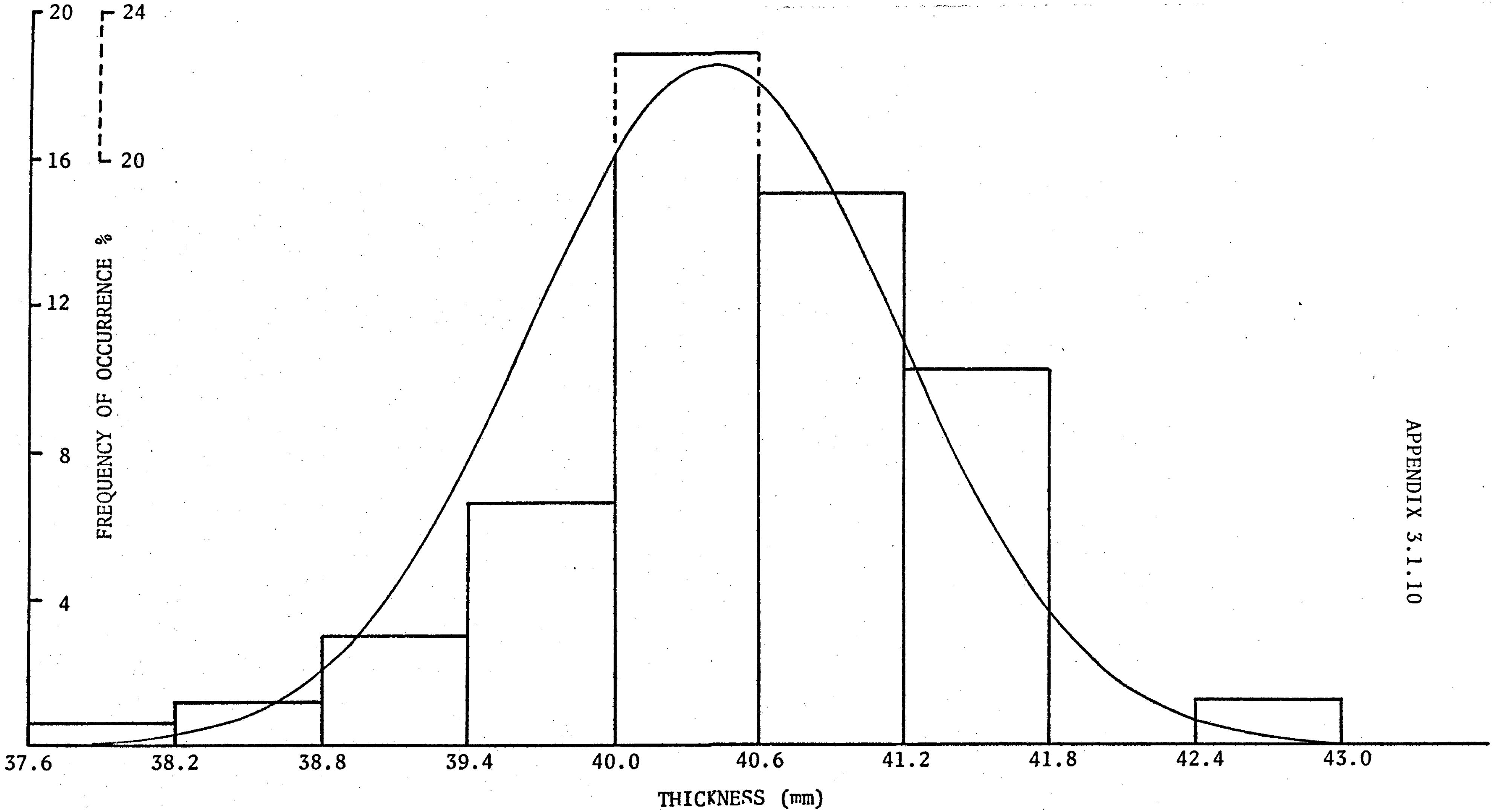
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 1. 38.1 mm nominal thickness.

APPENDIX 3.1.9



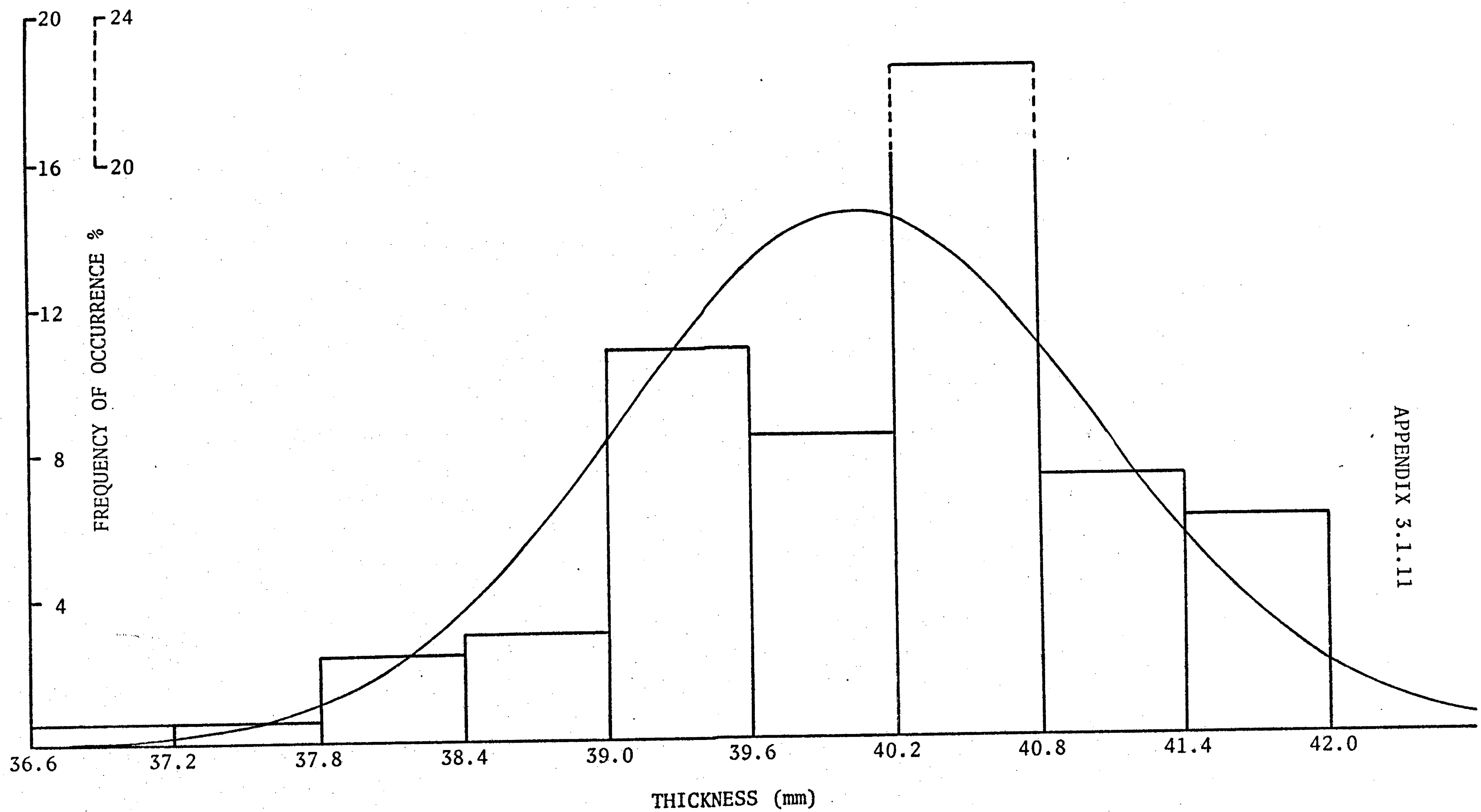
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 2. 38.1 mm nominal thickness.

APPENDIX 3.1.10



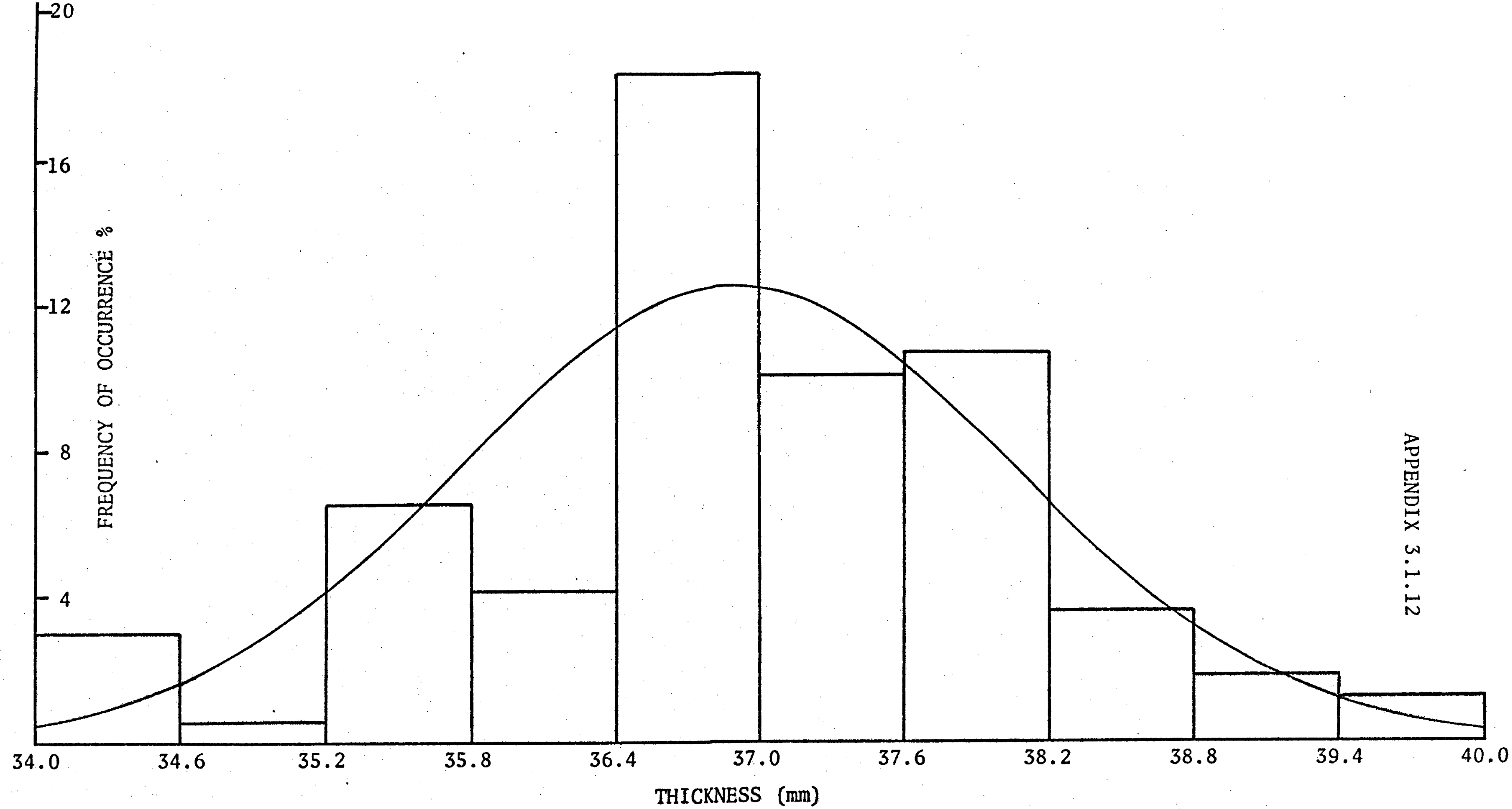
Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 3. 38.1 mm nominal thickness.

APPENDIX 3.1.11



Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 4. 38.1 mm nominal thickness.

APPENDIX 3.1.12



Histogram of measured thicknesses and normal distribution of timber thickness.
Sawmill No. 5. 38.1 mm nominal thickness.

APPENDIX 3.2

Matrix for synthesizing joints.
Sawmill No. 3.

(Based on Table 3.3)

THICKNESS mm		37.8	38.3	38.8	39.3	39.8	40.3	40.8	41.3	41.8	42.3	42.8
	EXPECTED OCCURRENCE	1	2	7	16	27	34	35	26	15	6	2
37.8	1											
38.3	2											
38.8	7											
39.3	16											
39.8	27											
40.3	34											
40.8	35											
41.3	26	26										
41.8	15	15	30									
42.3	6	6	12	42								
42.8	2	2	4	14	32							
Total	171											

Difference in Thickness mm	No. of Occurrences	
5.0	2(2) = 4 in 29,240	1 in 7300
4.5	4 + 2(6 + 4) = 24	1 in 1220
4.0	24 + 2(15 + 12 + 14) = 106	1 in 276
3.5	106 + 2(26 + 30 + 42 + 32) = 366	1 in 80